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STRUCTURAL INTEGRITY RECORDING SYSTEM (SIRS) FOR U.S. ARMY AH-1G HELICOPTERS

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report was prepared by Technology Incorporated under Contract DAAJ02-75-C-0050. The report documents the design, fabrication, and testing of a Structural Integrity Recording System (SIRS). The SIRS is a total system including a flight recorder, data retrieval unit, and computer software that permits calculation of dynamic component fatigue lives based on the monitored flight condition spectrum of the AH-1G aircraft. Results of this program provide the design data required to develop usage spectrum recording systems for Army helicopters.

Duane M. Saylor of the Structures Technical Area, Aeronautical Technology Division, served as project engineer on this effort.

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FATIGUE DAMAGE MONITORING	MECHANICAL COMPONENTS
DATA ACQUISITION	TEST and EVALUATION

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A Structural Integrity Recording System (SIRS) was designed and developed to track the fatique damage accumulation on 10 critical helicopter components for the subsequent timely replacement of such components for safer and more economical helicopter operation. SIRS comprises three discrete but interrelated subsystems: an airborne microprocessor-based recorder, a portable flight-line data retrieval unit, and a software system. The validation of SIRS, initially configured for the AH-1G helicopter, consisted of two phases.

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Phase I (Development Test and Evaluation - DT&E) covered the design, fabrication, laboratory qualification testing, reliability analysis, and flight-testing of the prototype SIRS recorder. Phase II (Initial Operational Test and Evaluation - IOT&E) covered the evaluation of the entire system operation and the resultant data acquired during a 3-month recording period with five AH-1G's, each equipped with a SIRS recorder. As the documentation of both DT&E and IOT&E, this report describes the characteristics and functions of the entire system and details the successful performance of the SIRS recorder in the laboratory qualification testing and the flight environment. The SIRS recorder performed as designed, operated reliably, and yielded valid data.

PREFACE

Technology Incorporated, Dayton, Ohio, prepared this report to document the results of validation of the operation of the Structural Integrity Recording System (SIRS). This report covers those activities conducted under Contract DAAJ02-75-C-0050, which was sponsored by the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia. The Army project monitor was Mr. Duane Saylor.

The principal Technology Incorporated personnel on this program were T. G. Farrell, program manager; R. B. Johnson, systems engineer; M. C. Tyler, principal design engineer; G. E. Brazier, principal software programmer; T. L. Cox, flight test engineer; and C. A. Shope, data analysis manager.

Acknowledgement is given to Captain W. Benjamin and Captain J. Pepper, U. S. Army Aviation Test Board, Fort Rucker, Alabama, who supported the Development Test and Evaluation flight test program and contributed to its timely completion. In addition, appreciation is extended to Mr. M. L. Wilker who served as test coordinator during the Initial Operational Test Evaluation flight test program.

The knowledgeable support of Mr. Duane Saylor in his role as project monitor is recognized. His effective direction was central to all activities culminating in the events documented in this report.

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CHAPTER 1.

INTRODUCTION

There is an ever-increasing emphasis throughout the Department of Defense (DoD) on reducing the costs and improving the effectiveness of military equipment. Constraints on military budgets, coupled with inflation and mounting operation and support costs, are prompting a search for positive methods of cost reduction in the acquisition and life cycle of all vehicles and equipment. The traditional effort has been a comprehensive reliability-improvement program involving parts screening, predictions, more stringent specifications, and rigorous demonstration and acceptance testing. While some improvements have been made, such programs have produced less than the desired overall result.

The effort reported here represents one element of a new initiative by the U. S. Army Applied Technology Laboratory to reduce Operating and Support (O&S) costs for Army helicopters.

PURPOSE

U. S. Army Contract DAAJ02-75-C-0050 was performed to develop, qualify, flight test, and demonstrate the Structural Integrity Recording System (SIRS). SIRS incorporates advanced technology hardware to provide a cost-effective method of tracking the accumulation of fatigue damage on critical helicopter dynamic components. The system monitors the variations in fleet utilization on a helicopter-by-helicopter basis so that helicopter components may be replaced according to helicopter usage for safer and more economical operation. The high-value, fatigue-sensitive components selected for the SIRS Development Test and Evaluation (DT&E) and Initial Operational Test & Evaluation (IOT&E) are identified in Table 1. These components were carefully selected since they have been found to be O&S cost drivers through years of service experience that includes operations in Southeast Asia. Illustrations of these components may be seen in Figures 1 through 6. They represent three elements of the AH-1G fatigue-sensitive dynamic assemblies, which are:

- Main Rotor Hub and Blade Assembly
- Main Rotor Control System
- Tail Rotor and Control System

Figure 1. AH-1G Helicopter.

Main Rotor Hub and Blade Assy

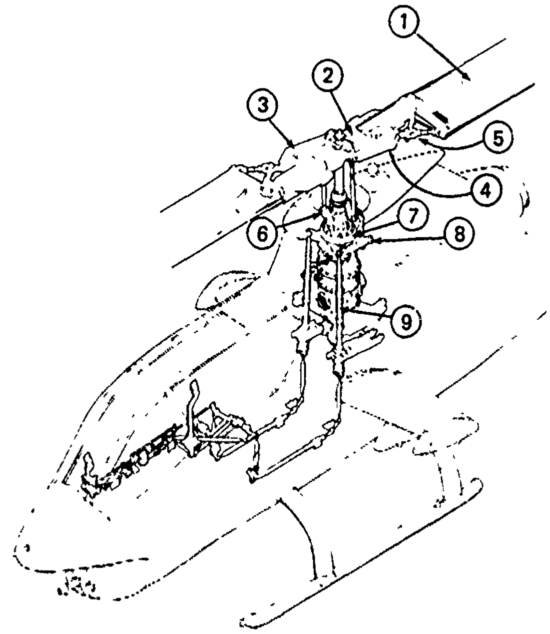
1. Main Rotor Blade
2. Main Rotor Yoke Extension
3. Main Rotor Grip
4. Main Rotor Pitch Horn
5. Main Rotor Retention Strap Fitting/Nut

Main Rotor Control System

6. Swashplate Drive Link (Scissors Assy)
7. Swashplate Outer Ring
8. Swashplate Inner Ring
9. Hydraulic Boost Cylinder Assy

Tail Rotor and Control System

10. Tail Rotor Blade



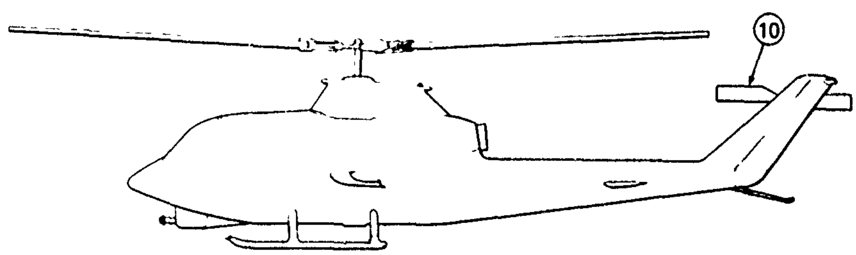


Figure 2. Location of Selected Fatigue-Critical Components for the AH-1G/SIRS Program. (TH-1 helicopter shown)

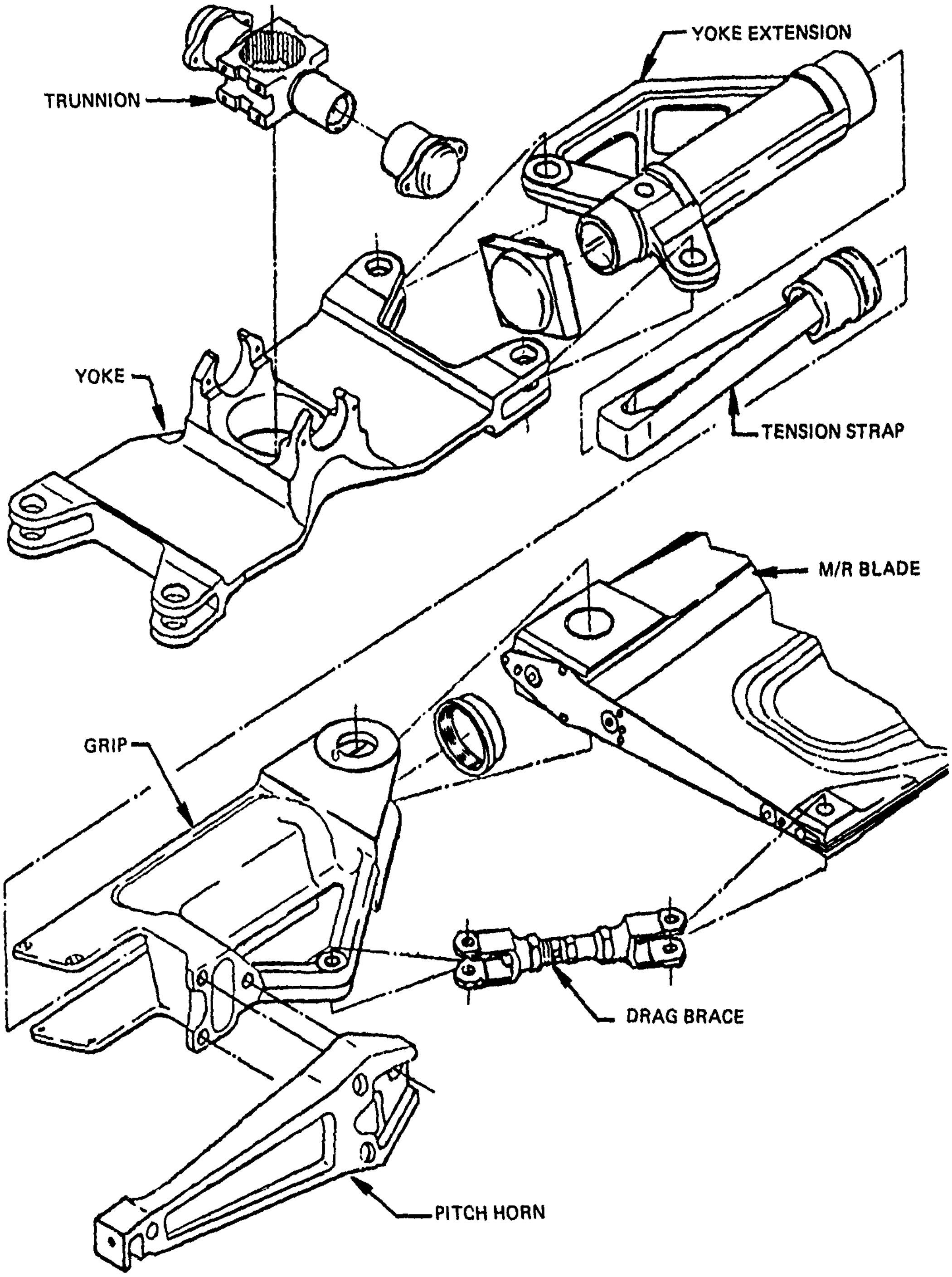


Figure 3. Main Rotor Hub and Blade Assembly.

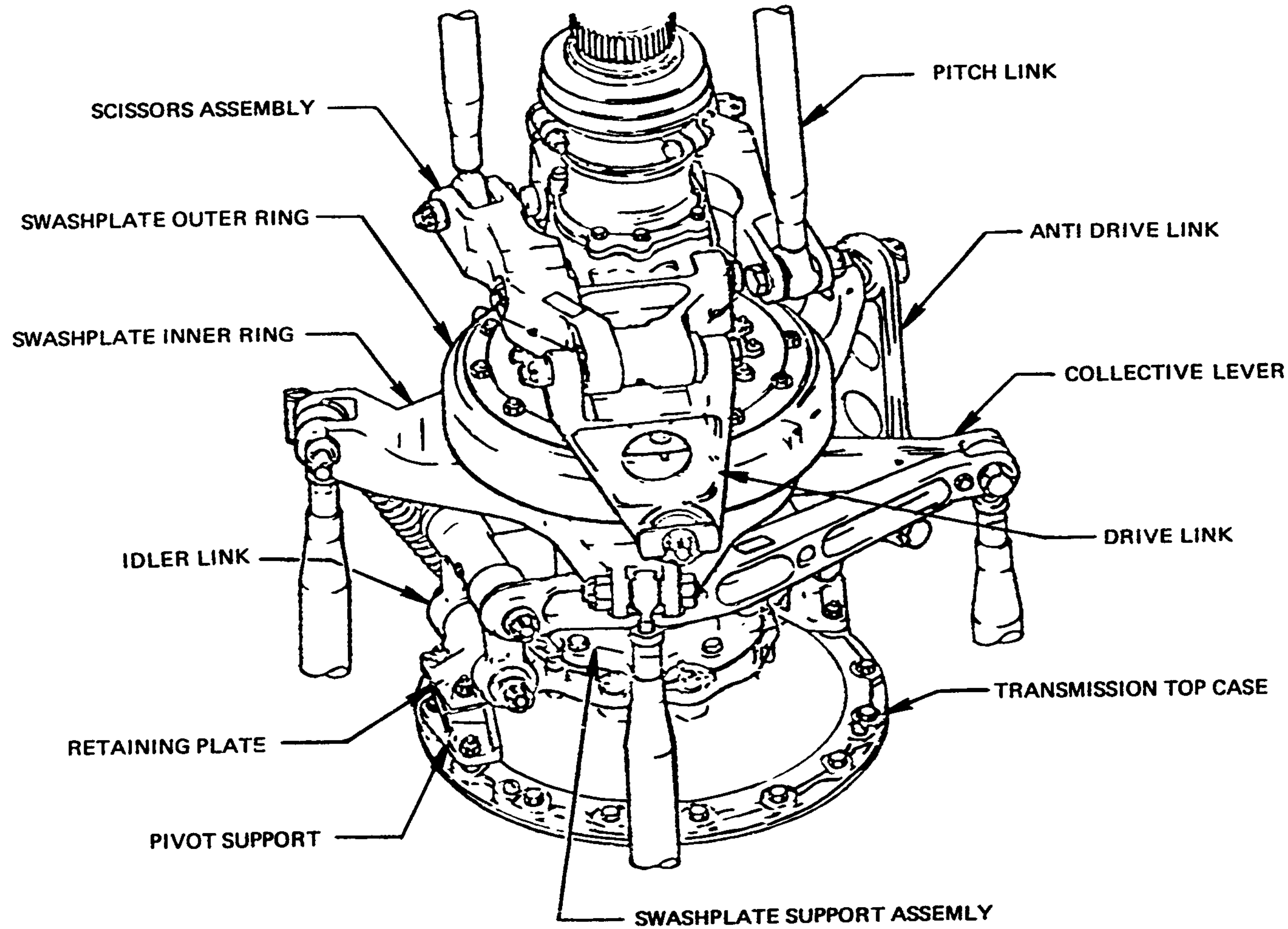


Figure 4. Main Rotor Control System.

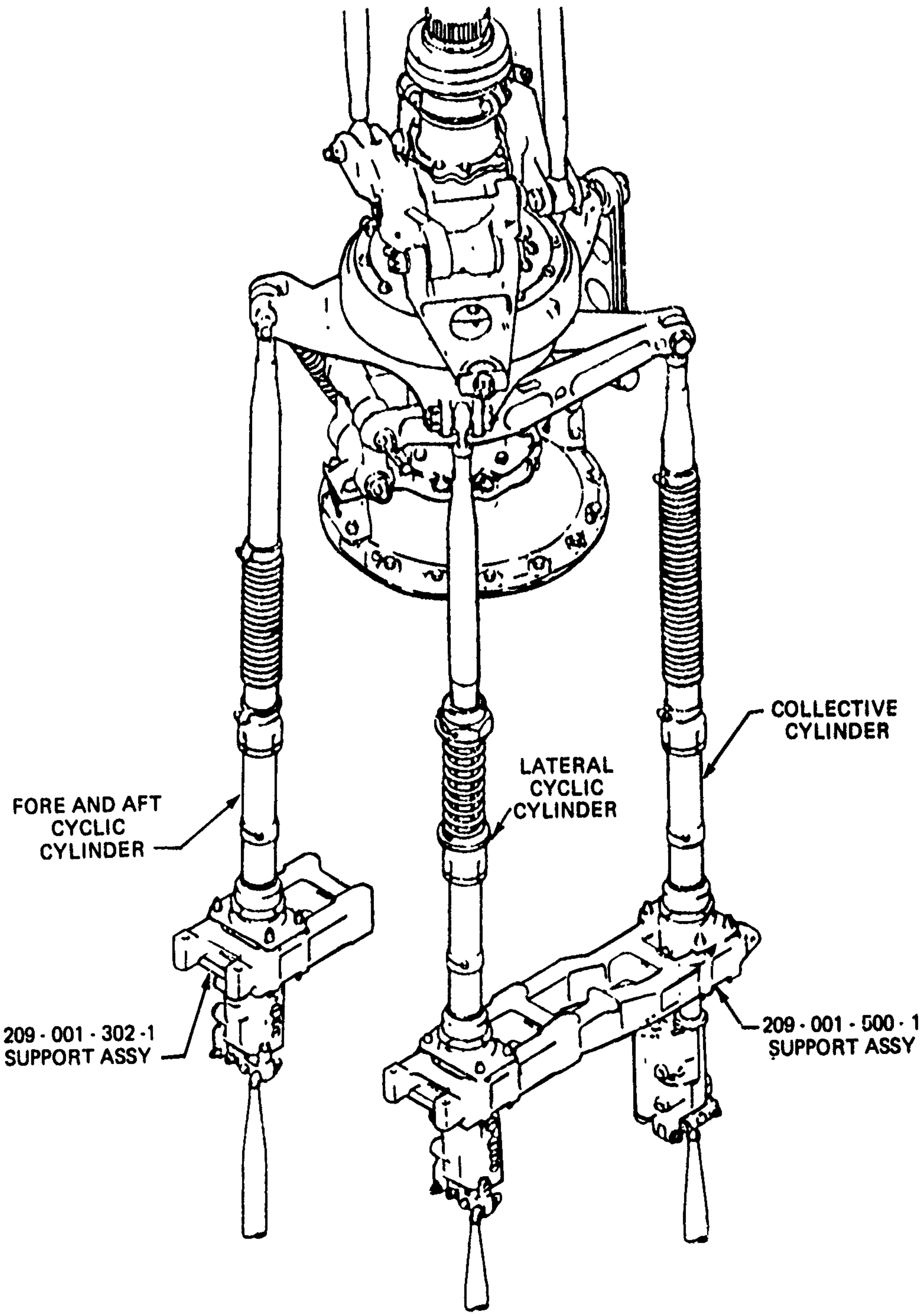


Figure 5. Hydraulic Boost Cylinders and Supports.

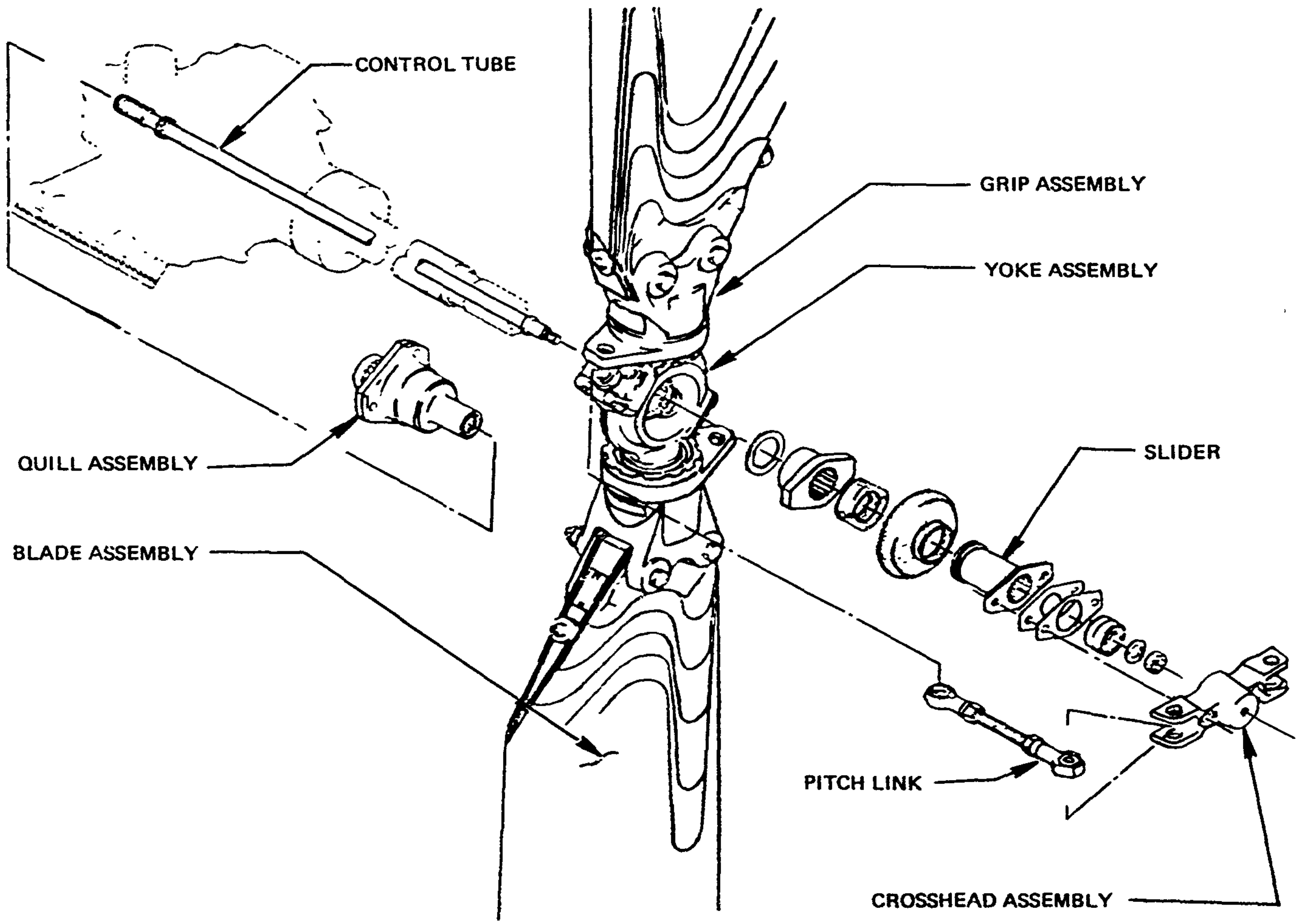


Figure 6. AH-1G Tail Rotor Components

TABLE 1. SELECTED FATIGUE-CRITICAL COMPONENTS FOR THE AH-1G HELICOPTER/SIRS PROGRAM

Nomenclature	Part Number
Main Rotor Blade	540-011-250-1
Main Rotor Yoke Extension	540-011-102-13, -15
Main Rotor Grip	540-011-154-5
Main Rotor Pitch Horn	209-010-109-5
M/R Retention Strap Fitting/Nut	540-011-113-1, -177-1
Swashplate Drive Link	209-010-408-7
Swashplate Outer Ring	209-010-403-1
Swashplate Inner Ring	209-010-402-1
Hydraulic Boost Cylinder Assy	209-076-021-1, -3, -5
Tail Rotor Blade	204-011-702-17

SIRS OVERVIEW

SIRS is a total system comprising an airborne microprocessor-based recorder, a portable flight-line retrieval unit, and a data processing package. The recorder monitors various flight parameters and stores preselected types of operational data within the recorder's solid-state memory. Data are retrieved by a portable flight-line retrieval unit that transfers the recorded data onto removable, miniature, computer-compatible tape cassettes. Each cassette can store the average monthly operational data of 50 helicopters. The data are processed and analyzed automatically by a software system that prints out the results in specifically formatted reports.

APPROACH

The contract performance consisted of two phases. Phase I (DT&E) covered these phases of SIRS: design, fabrication, qualification testing, reliability analysis, and flight testing at Fort Rucker, Alabama, on an AH-1G helicopter. The ultimate objective of Phase I was to verify that the SIRS recorder and data retrieval unit functioned as designed, operated reliably, and yielded accurate data.

In order to determine the fatigue life of any structure, three basic factors must be known. These factors are (1) some knowledge of the fatigue characteristics of the structure, (2) a knowledge of the loads or stresses to be expected in flight, and (3) a knowledge of the frequency of occurrence of these loads or stresses.

The information to fulfill the first item is obtained from the fatigue test program and the information to fulfill the second item is available from the flight loads survey. Information to fulfill the third basic requirement is the

purpose of SIRS. Thus, Phase II (IOT&E) was intended to evaluate the entire SIRS in a practical application. To this end, the SIRS recorder was installed in each of five AH-1G helicopters at Fort Rucker, Alabama, while these helicopters performed normal operations during a 3-month period. During Phase II, all processes in the SIRS were evaluated: the in-flight recording and data storage, the data retrieval, and the data processing and analyses. Finally, the resultant data in prescribed formats were evaluated to determine (1) their validity in representing incremental damage rates for the respective helicopter components and (2) their usefulness in indicating the times at which the various components should be replaced.

PROGRAM EXECUTION

Contract DAAJ02-75-C-0050 was issued 26 June 1975 on a cost-plus-fixed-fee basis. The estimated manpower requirement was 31,029 man-hours. The contract was modified eight times during the performance period. These modifications essentially involved detail changes. Residual Government property was transferred to Contract DAAJ02-77-C-0079 upon completion of this effort. Technical objectives were met, and should result in a more cost-effective execution of the Army attack helicopter program through the 1990's time frame. The feasibility of using a flight condition monitoring concept to extend the service life of high-cost parts on the AH-1G fleet was demonstrated. The effort provides a continuum between phasedown of the AH-1G project and initiation of the AH-1S technical support program.

CHAPTER 2.

SYSTEM DEFINITION

INTRODUCTION

As demonstrated in Reference 1, the flight condition monitoring (FCM) method can be used to assess the fatigue damage accrued in critical helicopter dynamic components. The development of an FCM system requires first defining given flight conditions (which describe the mission profile) in terms of flight parameter ranges and then establishing flight condition categories (representing one or more flight conditions) that account for the entire spectrum of fatigue-damaging flight operations. By monitoring the time spent in each flight condition category, the damage accrued by each component may be assessed on the basis of actual operation.

The following sections describe the FCM methodology as well as the development of an FCM system for the AH-1G helicopter.

FLIGHT CONDITION MONITORING METHODOLOGY

The FCM method of fatigue damage assessment is structured as follows: Defined in terms of specific combinations of flight parameter ranges, each flight condition category (FCC) represents one or more flight conditions. The component damage due to each flight condition may be determined when the loads during the flight condition, the number of flight occurrences, and the component fatigue strength are known. To ensure that the damage rate for each flight condition category is conservative, the maximum flight condition damage rate within the given flight condition category is chosen. Then the component damage accrued during a given recording period may be computed by Equation (1), and the flight condition category incremental damage may be summed to yield the total component damage. The total recorded time is calculated by Equation (2), and the fatigue life is predicted by Equation (3).

---

1. Johnson, R.B., Martin, G.L., and Moran, M.S., A FEASIBILITY STUDY FOR MONITORING SYSTEMS OF FATIGUE DAMAGE TO HELICOPTER COMPONENTS, Technology Incorporated; USAAMRDL Technical Report 74-92, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis Virginia, January 1975, AD A006641.

$$D = \sum_{k=1}^{m} D_k = \sum_{k=1}^{m} C_k T_k \tag{1}$$

$$T_t = \sum_{k=1}^{m} T_k \tag{2}$$

$$FL = \frac{T_t}{D} \tag{3}$$

where D = total damage to a component during the usage spectrum

D_k = component damage accrued during the kth flight condition category

C_k = damage rate in kth flight condition category for a particular component

T_k = amount of flight time spent in kth flight condition category

T_t = total flight time

FL = component fatigue life

m = number of flight condition categories

The FCM method of fatigue damage assessment requires analyzing the manufacturer's fatigue analysis to first define a technically feasible FCM system and then to establish damage rates for each component in each flight condition category. After these data have been developed and substantiated, the selected flight parameters may be monitored to assess the accrued fatigue damage of critical helicopter dynamic components.

ELEMENTS OF AH-1G FATIGUE ANALYSIS PERTINENT TO FCM SYSTEM DEVELOPMENT

As discussed in Reference 2 and summarized in Table 2, the AH-1G design utilization spectrum is defined in terms of specific flight conditions and the percentage of flight time spent in these flight conditions.

2. Seibel, J., FATIGUE LIFE SUBSTANTIATION OF DYNAMIC COMPONENTS OF THE AH-1G HELICOPTER, Report No. 209-099-064, Bell Helicopter Company, Fort Worth, Texas, June 1968.

TABLE 2. DESIGN UTILIZATION SPECTRUM

Flight Conditions		% of Flight Time	
		Total	Gross Weight Breakdown
I. Ground Conditions			
A. Normal Start		0.5000	
B. Shutdown		0.5000	
II. IGE Maneuvers			
A. Takeoff			
1. Normal	L-GW		0.180
	M-GW		0.450
	H-GW		0.270
		0.9000	
2. Jump	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
B. Hovering			
1. Steady	L-GW		0.434
	M-GW		1.085
	H-GW		0.651
		2.1700	
2. Right Turn	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
3. Left Turn	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
4. Control Correction			
(A) Longitudinal	L-GW		0.002
	M-GW		0.005
	H-GW		0.003
		0.0100	
(B) Lateral	L-GW		0.002
	M-GW		0.005
	H-GW		0.003
		0.0100	
(C) Rudder	L-GW		0.002
	M-GW		0.005
	H-GW		0.003
		0.0100	
C. Sideward Flight			
1. To the Right	L-GW		0.050
	M-GW		0.125
	H-GW		0.075
		0.2500	
2. To the Left	L-GW		0.050
	M-GW		0.125
	H-GW		0.075
		0.2500	
D. Rearward Flight	L-GW		0.050
	M-GW		0.125
	H-GW		0.075
		0.2500	

TABLE 2. Continued

Flight Conditions			% of Flight Time Total	Gross Weight Breakdown
E. Acceleration Hover to Climb A/S		L-GW		0.100
		M-GW		0.250
		H-GW		0.150
			0.5000	
F. Deceleration				
1. Normal		L-GW		0.140
		M-GW		0.350
		H-GW		0.210
			0.7000	
2. Quick Stop		L-GW		0.050
		M-GW		0.150
		H-GW		0.090
			0.3000	
G. Approach and Landing		L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	
III. Forward Level Flight				
Airspeed	RPM			
A. 0.50 VH	314	L-GW		0.100
		M-GW		0.250
		H-GW		0.150
			0.5000	
	324	L-GW		0.900
		M-GW		2.250
		H-GW		1.350
			4.5000	
B. 0.60 VH	314	L-GW		0.040
		M-GW		0.100
		H-GW		0.060
			0.2000	
	324	L-GW		0.360
		M-GW		0.900
		H-GW		0.540
			1.8000	
C. 0.70 VH	314	L-GW		0.060
		M-GW		0.150
		H-GW		0.090
			0.3000	
	324	L-GW		0.540
		M-GW		1.350
		H-GW		0.810
			2.7000	
D. 0.80 VH	314	L-GW		0.300
		M-GW		0.750
		H-GW		0.450
			1.5000	
	324	L-GW		2.700
		M-GW		6.750
		H-GW		4.050
			13.5000	

TABLE 2. Continued

Flight Conditions			% of Flight Time Total	% of Flight Time Gross Weight Breakdown
E. 0.90 VH	314	L-GW		0.500
		M-GW		1.250
		H-GW		0.750
			2.5000	
	324	L-GW		4.500
		M-GW		11.250
		H-GW		6.750
			22.5000	
F. VH	314	L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	
	324	L-GW		1.800
		M-GW		4.500
		H-GW		2.700
			9.0000	
IV. Non-Firing Maneuvers				
A. Full Power Climb				
1. Normal		L-GW		0.800
		M-GW		2.000
		H-GW		1.200
			4.0000	
2. High-Speed		L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	
B. Maximum Rate Accel. Climb - Cruise A/S		L-GW		0.560
		M-GW		1.400
		H-GW		0.840
			2.8000	
C. Normal Turns				
1. To the Right				
(A) 0.5 VH		L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	
(B) 0.7 VH		L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	
(C) 0.9 VH		L-GW		0.400
		M-GW		1.000
		H-GW		0.600
			2.0000	
2. To the Left				
(A) 0.5 VH		L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	

TABLE 2. Continued

Flight Conditions		% of Flight Time: Total	% of Flight Time: Gross Weight Breakdown
(B) 0.7 VH	L-GW		0.200
	M-GW		0.500
	H-GW		0.300
		1.0000	
(C) 0.9 VH	L-GW		0.400
	M-GW		1.000
	H-GW		0.600
		2.0000	
D. 0.9 VH Control Corr.			
1. Longitudinal	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
2. Lateral	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
3. Rudder	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
E. Sideslip	L-GW		0.100
	M-GW		0.250
	H-GW		0.150
		0.5000	
F. Part Power Descent	L-GW		0.510
	M-GW		1.275
	H-GW		0.765
		2.5500	
V. Gunnery Maneuvers			
A. Firing in a Hover	L-GW		0.015
	M-GW		0.038
	H-GW		0.023
		0.0750	
B. Strafing in Accel. From a Hover	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
C. Gunnery Runs			
1. Point Target Runs			
(A) To 0.6 VL	L-GW		0.056
	M-GW		0.140
	H-GW		0.084
		0.2800	
(B) To 0.8 VL	L-GW		0.168
	M-GW		0.420
	H-GW		0.252
		0.8400	
(C) To 0.9 VL	L-GW		0.280
	M-GW		0.700
	H-GW		0.420
		1.4000	

TABLE 2. Continued

Flight Conditions		% of Flight Time: Total	% of Flight Time: Gross Weight Breakdown
(D) To VL	L-GW		0.056
	M-GW		0.140
	H-GW		0.084
		0.2800	
2. Spray Fire Dives			
(A) To 0.6 VL	L-GW		0.024
	M-GW		0.060
	H-GW		0.036
		0.1200	
(B) To 0.8 VL	L-GW		0.072
	M-GW		0.180
	H-GW		0.108
		0.3600	
(C) To 0.9 VL	L-GW		0.120
	M-GW		0.300
	H-GW		0.180
		0.6000	
(D) To VL	L-GW		0.024
	M-GW		0.060
	H-GW		0.036
		0.1200	
D. Gunnery Run Pullup			
1. To the Right			
(A) 0.6 VL	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
(B) 0.8 VL	L-GW		0.060
	M-GW		0.150
	H-GW		0.090
		0.3000	
(C) 0.9 VL	L-GW		0.100
	M-GW		0.250
	H-GW		0.150
		0.5000	
(D) VL	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
2. To the Left			
(A) 0.6 VL	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
(B) 0.8 VL	L-GW		0.060
	M-GW		0.150
	H-GW		0.090
		0.3000	
(C) 0.9 VL	L-GW		0.100
	M-GW		0.250
	H-GW		0.150
		0.5000	

TABLE 2. Continued

Flight Conditions		% of Flight Time: Total	% of Flight Time: Gross Weight Breakdown
(D) VL	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
3. Symmetrical			
(A) 0.6 VL	L-GW		0.002
	M-GW		0.005
	H-GW		0.003
		0.0100	
(B) 0.8 VL	L-GW		0.006
	M-GW		0.015
	H-GW		0.009
		0.0300	
(C) 0.9 VL	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
(D) VL	L-GW		0.002
	M-GW		0.005
	H-GW		0.003
		0.0100	
E. Gunnery Turns			
1. To the Right			
(A) 0.5 VH	L-GW		0.075
	M-GW		0.188
	H-GW		0.113
		0.3750	
(B) 0.7 VH	L-GW		0.075
	M-GW		0.188
	H-GW		0.113
		0.3750	
(C) 0.9 VH	L-GW		0.150
	M-GW		0.375
	H-GW		0.225
		0.7500	
2. To the Left			
(A) 0.5 VH	L-GW		0.075
	M-GW		0.188
	H-GW		0.113
		0.3750	
(B) 0.7 VH	L-GW		0.075
	M-GW		0.188
	H-GW		0.113
		0.3750	
(C) 0.9 VH	L-GW		0.150
	M-GW		0.375
	H-GW		0.225
		0.7500	

TABLE 2. Continued

Flight Conditions		Total (% of Flight Time)	Gross Weight Breakdown (% of Flight Time)
F. S-Turns			
1. At 0.8 VH	L-GW		0.040
	M-GW		0.100
	H-GW		0.060
		0.2000	
2. At VH	L-GW		0.015
	M-GW		0.038
	H-GW		0.022
		0.0750	
VI. Power Transitions			
A. Power to Auto			
1. 0.5 VH	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
2. 0.7 VH	L-GW		0.025
	M-GW		0.063
	H-GW		0.038
		0.1250	
3. 0.9 VH	L-GW		0.035
	M-GW		0.088
	H-GW		0.053
		0.1750	
B. Auto to Power			
1. In Ground Effect	L-GW		0.030
	M-GW		0.075
	H-GW		0.045
		0.1500	
2. 0.4 VH	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
3. 0.6 VH	L-GW		0.015
	M-GW		0.038
	H-GW		0.023
		0.0750	
4. Max Auto A/S	L-GW		0.005
	M-GW		0.013
	H-GW		0.008
		0.0250	
VII. Autorotation			
A. Stabilized Flight			
1. 0.4 VH	L-GW		0.040
	M-GW		0.100
	H-GW		0.060
		0.2000	
2. 0.6 VH	L-GW		0.280
	M-GW		0.700
	H-GW		0.420
		1.4000	

TABLE 2. Concluded

Flight Conditions		% of Flight Time: Total	% of Flight Time: Gross Weight Breakdown
3. Max Auto A/S	L-GW		0.060
	M-GW		0.150
	H-GW		0.090
		0.3000	
B. Auto Turns			
1. To the Right			
(A) 0.4 VH	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
(B) 0.6 VH	L-GW		0.080
	M-GW		0.200
	H-GW		0.120
		0.4000	
(C) Max Auto A/S	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
2. To the Left			
(A) 0.4 VH	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
(B) 0.6 VH	L-GW		0.080
	M-GW		0.200
	H-GW		0.120
		0.4000	
(C) Max Auto A/S	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
C. Auto Landing	L-GW		0.050
	M-GW		0.125
	H-GW		0.075
		0.2500	

The manufacturer assumed that the AH-1G operational time would be distributed as follows in three gross weight ranges: (1) 20 percent in a light gross weight (L-GW) range (less than 7750 pounds), (2) 50 percent in a middle gross weight (M-GW) range (7750 to 8750 pounds), and (3) 30 percent in a high gross weight (H-GW) range (more than 8750 pounds). This gross weight distribution was also used in the preliminary development of the FCM system for the AH-1G.

The fatigue-critical AH-1G components to be used in the FCM method were selected by determining those major life-limited components in the main and tail rotor systems that have a significant effect on the AH-1G life-cycle cost. As a result, 10 components were selected. For each of these components, Table 3 lists the part number along with the manufacturer-computed fatigue life and the recommended retirement life. The component fatigue damage data along with other information (e.g., component loads data and component S/N data) needed for performing a fatigue analysis were extracted from the fatigue substantiation report (Reference 2).

TABLE 3. SELECTED FATIGUE-CRITICAL COMPONENTS FOR THE AH-1G HELICOPTER

Nomenclature	Part Number	Calculated Fatigue Life(hr)	Recommended Retirement Life (hr)
Main Rotor Blade	540-011-250-1	2,792	1,100
Main Rotor Yoke Extension	540-011-102-13,15	10,633	3,300
Main Rotor Grip	540-011-154-5	95,057	--
Main Rotor Pitch Horn	209-010-109-5	9,105	6,600
M/R Retention Strap Fitting/Nut	540-011-113-1,-177-1	2,760	2,200
Swashplate Drive Link	209-010-408-7	13,953	11,000
Swashplate Outer Ring	209-010-403-1	9,806	3,300
Swashplate Inner Ring	209-010-402-1	10,453	3,300
Hydraulic Boost Cylinder Assy	209-076-021-1,3,5	3,345	3,300
Tail Rotor Blade	204-011-702-17	3,764	1,100

TECHNICAL ACCEPTANCE CRITERIA FOR FCM SYSTEMS

Basic Definition of Technical Acceptance Criteria

In the development of the FCM system for the AH-1G, the technical acceptance criteria developed in Reference 1 were applied to several candidate systems.

According to these criteria, an FCM system must be capable of predicting, for each component, fatigue lives that fall between a conservative lower bound and realistic upper bounds. One upper bound is defined for mild aircraft usage and another upper bound for severe aircraft usage (see Figure 7). The intent in these criteria of the upper bounds for both mild and severe conditions is to evaluate candidate FCM systems relative to the usage variations in the expected fleet operation spectrum.

The application of the technical acceptance criteria requires the following: (1) the definition of the lower bounds for the component fatigue lives, (2) the substantiation of a fatigue damage assessment model (specifically, the computer program FATHIP) that closely parallels the fatigue analysis used by the AH-1G manufacturer and which may be validly used in the applications discussed later in this section, and (3) the derivation of realistic upper bounds for the component fatigue lives in both a mild and a severe usage spectrum by applying the substantiated fatigue damage assessment model.

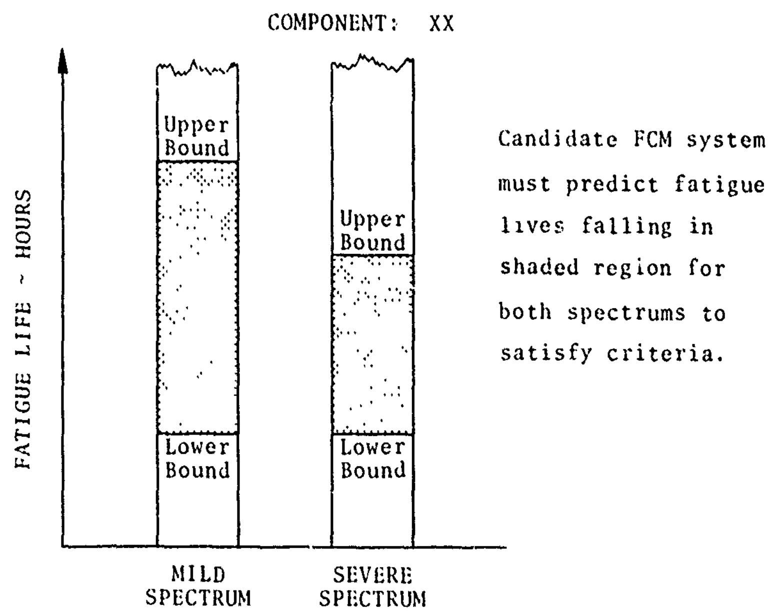


Figure 7. Depiction of Technical Acceptance Criteria.

Definition of Lower Bounds for Component Fatigue Lives

Table 3 includes the manufacturer-computed fatigue lives and the recommended retirement lives for the 10 selected components. The manufacturer's computations were based on the design utilization spectrum summarized in Table 2. Since such a spectrum is conventionally more severe than the actual usage anticipated during the helicopter life, the computed fatigue lives are conservative. As is apparent in Table 2, the recommended retirement lives are generally much shorter than the fatigue lives.

To conform with the philosophy in previous studies, the recommended retirement lives were defined as the lower bounds.

Substantiation of Fatigue Damage Assessment Model (FATHIP)

FATHIP, the fatigue damage assessment model used in the following applications, computes fatigue damage in a manner similar to the AH-1G manufacturer's process. To substantiate this model, the same component load, S/N, and frequency of occurrence data used in the manufacturer's computations were also used as input in FATHIP. Obviously, if FATHIP could yield fatigue lives agreeing closely with those derived by the manufacturer, the model would be substantiated.

For both the manufacturer and the FATHIP computations, Table 4 lists the fatigue damage accrued by each of the 10 selected AH-1G components during 100 hours of operation in the design utilization spectrum. The close correlation of the two sets of data verifies FATHIP as a valid fatigue damage assessment model for the AH-1G helicopter.

TABLE 4. COMPARISON OF MANUFACTURER AND FATHIP FATIGUE DAMAGE AND FATIGUE LIFE COMPUTATIONS

	Design Spectrum			
	Manufacturer's Computations*		FATHIP Results	
Component	Fatigue Damage in 100 hr	Fatigue Life (hr)	Fatigue Damage in 100 hr	Fatigue Life (hr)
Main Rotor Blade	0.035810	2,792	0.035806	2,793
Main Rotor Yoke Extension	0.009404	10,633	0.009403	10,635
Main Rotor Grip	0.001052	95,057	0.001053	95,012
Main Rotor Pitch Horn	0.010983	9,105	0.010982	9,106
M/R Retention Strap Fitting/Nut	0.036232	2,760	0.036232	2,760
Swashplate Drive Link	0.007167	13,953	0.007164	13,959
Swashplate Outer Ring	0.010197	9,806	0.010196	9,808
Swashplate Inner Ring	0.009566	10,453	0.009562	10,458
Hydraulic Boost Cylinders	0.029890	3,345	0.029895	3,345
Tail Rotor Blade	0.026567	3,764	0.026568	3,764

* Reference 2

Derivation of Upper Bounds for Component Fatigue Lives in Both Mild and Severe Utilization Spectra

Without regard at the outset to which might be the more severe spectrum, two utilization spectra were derived independently from separate sources: (1) the AH-1G operational usage data collected in Southeast Asia (Reference 3), and (2) the expected future mission utilization data for attack-type helicopters (also documented in Reference 3). As listed in Table 5, each spectrum was defined in terms of the same flight conditions that were used to define utilization spectrum. In addition, the gross weight distribution assumed in Reference 2 was used for each spectrum.

To assess the relative severity of the two utilization spectra from a fatigue damage standpoint, the two spectra were then processed in FATHIP to predict the fatigue life for each of the 10 selected components. On the basis of the resulting fatigue life predictions, the spectrum representing the Southeast Asia data was judged more severe than the spectrum representing the other data. Consequently, the former was termed the severe spectrum and the latter the mild spectrum. However, these spectra are not to be interpreted as worst-case usage, but rather as the mild and severe usage that would normally occur with some regularity.

The two sets of fatigue lives derived by FATHIP for each of the 10 selected components were defined as the upper fatigue life bounds, one set for the mild and the other set for the severe utilization spectrum. Table 6 lists these bounds. Since this table also includes the lower fatigue bounds as previously listed in Table 3, it summarizes the constraints for the application of the technical acceptance criteria to the candidate FCM systems for the AH-1G helicopter.

Therefore, to be considered technically acceptable, a candidate FCM system must be capable of predicting, for each component, a fatigue life within these bounds when the basic frequency of occurrence data in either the mild or the severe spectrum is the simulated output of an airborne FCM recorder.

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3. Cox, T.L., Johnson, R.B., and Russell, S.W., DYNAMIC LOADS AND STRUCTURAL CRITERIA, Technology Incorporated; USAAMRDL Technical Report 75-9, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, April 1975, AD A009759.

TABLE 5. MILD AND SEVERE SPECTRUM DEFINITIONS

	FLIGHT CONDITION		DESIGN	MILD	SEVERE
1	NORMAL START-SHUTDOWN (W/COLL.)	(IGE MANEUVER)	1.000	.290	.616
2	NORMAL TAKE-OFF	(IGE MANEUVER)	.900	2.558	.750
3	JUMP TAKE-OFF	(IGE MANEUVER)	.100	.656	.188
4	STEADY HOVER	(IGE MANEUVER)	2.170	11.530	12.958
5	HOVERING RIGHT TURN	(IGE MANEUVER)	.100	2.887	.817
6	HOVERING LEFT TURN	(IGE MANEUVER)	.100	2.887	.817
7	HOVERING LONGITUDINAL CONTROL CORR.	(IGE MANEUVER)	.010	.126	.027
8	HOVERING LATERAL CONTROL CORR.	(IGE MANEUVER)	.010	.126	.027
9	HOVERING RUDDER CONTROL CORR.	(IGE MANEUVER)	.010	.126	.027
10	SIDEWARD FLIGHT TO THE RIGHT	(IGE MANEUVER)	.250	2.110	.409
11	SIDEWARD FLIGHT TO THE LEFT	(IGE MANEUVER)	.250	2.110	.409
12	REARWARD FLIGHT	(IGE MANEUVER)	.250	1.600	.241
13	ACCELERATION HOVER TO CLIMB A S	(IGE MANEUVER)	.500	3.248	.456
14	NORMAL DECELERATION	(IGE MANEUVER)	.700	.823	2.519
15	QUICK STOP DECELERATION	(IGE MANEUVER)	.300	.823	2.519
16	APPROACH AND LANDING	(IGE MANEUVER)	1.000	.385	4.529
17	FORWARD LEVEL FLIGHT 0.50 VH AT 314 RPM		.500	1.550	1.260
18	FORWARD LEVEL FLIGHT 0.50 VH AT 324 RPM		4.500	.180	11.296
19	FORWARD LEVEL FLIGHT 0.60 VH AT 314 RPM		.200	1.040	1.206
20	FORWARD LEVEL FLIGHT 0.60 VH AT 324 RPM		1.800	.115	10.867
21	FORWARD LEVEL FLIGHT 0.70 VH AT 314 RPM		.300	.350	.657
22	FORWARD LEVEL FLIGHT 0.70 VH AT 324 RPM		2.700	.040	5.856
23	FORWARD LEVEL FLIGHT 0.80 VH AT 314 RPM		1.500	.171	.241
24	FORWARD LEVEL FLIGHT 0.80 VH AT 324 RPM		13.500	.020	2.171
25	FORWARD LEVEL FLIGHT 0.90 VH AT 314 RPM		2.500	.313	.013
26	FORWARD LEVEL FLIGHT 0.90 VH AT 324 RPM		22.500	.232	.157
27	FORWARD LEVEL FLIGHT VH AT 314 RPM		1.000	.010	.013
28	FORWARD LEVEL FLIGHT VH AT 324 RPM		9.000	.001	.161
29	NORMAL FULL POWER CLIMB		4.000	5.375	6.172
30	HIGH-SPEED FULL POWER CLIMB		1.000	2.190	2.644
31	MAX. RATE ACCEL. FULL POWER CLIMB TO CRUISE A S		2.800	2.848	8.154
32	NORMAL RIGHT TURN AT 0.5 VH		1.000	6.122	1.116
33	NORMAL RIGHT TURN AT 0.7 VH		1.000	2.188	1.116
34	NORMAL RIGHT TURN AT 0.9 VH		2.000	.438	.248
35	NORMAL LEFT TURN AT 0.5 VH		1.000	5.671	1.116
36	NORMAL LEFT TURN AT 0.7 VH		1.000	2.026	1.116
37	NORMAL LEFT TURN AT 0.9 VH		2.000	.406	.248
38	LONGITUDINAL CONTROL CORR. AT 0.9 VH		.050	.050	.001
39	LATERAL CONTROL CORR. AT 0.9 VH		.050	.050	.001
40	RUDDER CONTROL CORR. AT 0.9 VH		.050	.050	.001
41	SIDESLIP		.500	.113	.013
42	PART POWER DESCENT		2.550	6.471	7.679
43	FIRING IN A HOVER		.075	19.047	.230
44	STRAFING IN ACCEL. FROM A HOVER		.050	.672	.270

TABLE 5. Concluded

	FLIGHT CONDITION	DESIGN	MILD	SEVERE
45	GUNNERY RUN-PT. TARGET DIVE AT 0.6 VL	.280	.656	.734
46	GUNNERY RUN-PT. TARGET DIVE AT 0.8 VL	.840	.252	.734
47	GUNNERY RUN-PT. TARGET DIVE AT 0.9 VL	1.400	.051	.201
48	GUNNERY RUN-PT. TARGET DIVE AT VL	.280	.051	.201
49	GUNNERY RUN-SPRAY FIRE DIVE AT 0.6 VL	.120	.656	1.136
50	GUNNERY RUN-SPRAY FIRE DIVE AT 0.8 VL	.360	.252	1.136
51	GUNNERY RUN-SPRAY FIRE DIVE AT 0.9 VL	.600	.051	.300
52	GUNNERY RUN-SPRAY FIRE DIVE AT VL	.120	.051	.300
53	GUNNERY RUN-P/U TO THE RIGHT AT 0.6 VL	.100	.249	.440
54	GUNNERY RUN-P/U TO THE RIGHT AT 0.8 VL	.300	.249	.450
55	GUNNERY RUN-P/U TO THE RIGHT AT 0.9 VL	.500	.062	.120
56	GUNNERY RUN-P/U TO THE RIGHT AT VL	.100	.062	.110
57	GUNNERY RUN-P/U TO THE LEFT AT 0.6 VL	.100	.249	.440
58	GUNNERY RUN-P/U TO THE LEFT AT 0.8 VL	.300	.249	.450
59	GUNNERY RUN-P/U TO THE LEFT AT 0.9 VL	.500	.062	.120
60	GUNNERY RUN-P/U TO THE LEFT AT VL	.100	.062	.110
61	GUNNERY RUN-P/U(SYMMETRICAL) AT 0.6 VL	.010	.055	.100
62	GUNNERY RUN-P/U(SYMMETRICAL) AT 0.8 VL	.030	.055	.100
63	GUNNERY RUN-P/U(SYMMETRICAL) AT 0.9 VL	.050	.014	.025
64	GUNNERY RUN-P/U(SYMMETRICAL) AT VL	.010	.014	.025
65	GUNNERY TURN TO THE RIGHT AT 0.5 VH	.375	1.375	.248
66	GUNNERY TURN TO THE RIGHT AT 0.7 VH	.375	1.375	.198
67	GUNNERY TURN TO THE RIGHT AT 0.9 VH	.750	.306	.100
68	GUNNERY TURN TO THE LEFT AT 0.5 VH	.375	1.375	.248
69	GUNNERY TURN TO THE LEFT AT 0.7 VH	.375	1.375	.198
70	GUNNERY TURN TO THE LEFT AT 0.9 VH	.750	.306	.100
71	GUNNERY S-TURN AT 0.8 VH	.200	.330	.150
72	GUNNERY S-TURN AT VH	.075	.037	.099
73	POWER TO AUTO. TRANSITION AT 0.5 VH	.050	.007	.007
74	POWER TO AUTO. TRANSITION AT 0.7 VH	.125	.013	[illegible]
75	POWER TO AUTO. TRANSITION AT 0.9 VH	.175	.013	.013
76	AUTO. TO POWER TRANSITION IGE	.150	.007	.007
77	AUTO. TO POWER TRANSITION AT 0.4 VH	.100	.010	.010
78	AUTO. TO POWER TRANSITION AT 0.6 VH	.075	.007	.007
79	AUTO. TO POWER TRANSITION AT MAX. AUTO. A/S	.025	.003	.003
80	STABILIZED AUTO. FLIGHT AT 0.4 VH	.200	.004	.004
81	STABILIZED AUTO. FLIGHT AT 0.6 VH	1.400	.012	.012
82	STABILIZED AUTO. FLIGHT AT MAX. AUTO. A/S	.300	.004	.004
83	AUTO. TURN TO THE RIGHT AT 0.4 VH	.050	.001	.001
84	AUTO. TURN TO THE RIGHT AT 0.6 VH	.400	.002	.002
85	AUTO. TURN TO THE RIGHT AT MAX. AUTO. A/S	.050	.001	.001
86	AUTO. TURN TO THE LEFT AT 0.4 VH	.050	.001	.001
87	AUTO. TURN TO THE LEFT AT 0.6 VH	.400	.002	.002
88	AUTO. TURN TO THE LEFT AT MAX. AUTO. A/S	.050	.001	.001
89	AUTOROTATION LANDING	.250	.007	.007
		100.000	100.000	100.000

TABLE 6. UPPER AND LOWER BOUNDS FOR TECHNICAL ACCEPTANCE CRITERIA

Component	Lower Fatigue Life Bounds Recommended Lives	Upper Fatigue Life Bounds Mild Spectrum	Upper Fatigue Life Bounds Severe Spectrum
Main Potor Blade	1,100	4,307	3,542
Main Rotor Yoke Extension	3,300	24,917	14,779
Main Rotor Grip	Unlimited	190,042	69,686
Main Rotor Pitch Horn	6,600	17,953	10,596
M/R Retention Strap Ftg./Nut	2,200	9,517	4,488
Swashplate Drive Link	11,000	27,353	16,513
Swashplate Outer Ring	3,300	18,707	12,325
Swashplate Inner Ring	3,300	25,128	15,481
Hydraulic Boost Tube	3,300	8,635	5,145
Tail Rotor Blade	1,100	12,106	7,192

DEVELOPMENT OF A CANDIDATE FCM SYSTEM FOR THE AH-1G HELICOPTER

The development of a candidate FCM system for the AH-1G helicopter requires the following procedure: (1) the identification of those flight conditions that have the greatest fatigue-damaging effect on the critical AH-1G components, (2) the ranking of the fatigue-damaging flight conditions according to both the degree of their damaging effects on the helicopter as a whole and the relative costs to replace the selected components, (3) the selection of the measurable flight parameters whose collective variations will characterize the flight conditions identified in (1), and (4) the final definition of an FCM system in terms of specific combinations of flight parameters and the threshold levels of these parameters.

The following sections summarize the analytical processes used in developing an FCM system for the AH-1G.

Flight-Condition Ranking

Of the 89 flight conditions (each with three gross weight ranges) identified in the AH-1G design fatigue spectrum, some are damaging to the 10 selected components in varying degrees while others are not damaging at all. Consequently, the damaging flight conditions had to be first identified and then ranked according to both the degree of their damaging effects on the helicopter as a whole and the costs to replace the selected components.

As was done previously in Reference 1, the fatigue-damaging (sensitivity) rank of each AH-1G flight condition was computed by Equation (4). With relative expense and complexity of the selected dynamic components being significant factors, this equation provides the means for representing each flight condition relative to its rate of producing fatigue damage to the helicopter as a whole. A normalized rank value was also computed by Equation (5). The results of the ranking procedure are shown in Table 7.

$$R = \sum_{\substack{\text{all} \\ \text{components}}} \left(C_F \cdot \left(\frac{L_R}{L_A}\right) \cdot n \cdot D\right) \tag{4}$$

$$\overline{R} = \frac{R}{t} \tag{5}$$

where R = sensitivity rank value

C_F = estimated relative cost factor for each component (each component was normalized to 1.0 for the main rotor blade)

$\frac{L_R}{L_A}$ = ratio of recommended life of each component to an assumed aircraft life of 7200 hours

n = number of components per aircraft

D = percentage of fatigue damage to each component due to a given flight condition

R = normalized rank value

t = flight condition frequency in the design usage spectrum

TABLE 7. RESULTS OF RANKING PROCEDURE

FLIGHT CONDITION	SENSITIVITY RANK VALUE	NORMALIZED RANK VALUE
Gunnery Run P/U (symmetrical) at VL	.4289	42.8916
Gunnery S-turn at VH	2.4017	32.0233
Gunnery Run P/U to the Left at VL	2.6629	26.6288
Gunnery Run P/U to the Right at VL	2.1912	21.9116
Gunnery Run P/U (symmetrical) at 0.9 VL	.7996	15.9910
Gunnery Run P/U to the Left at 0.9 VL	5.0312	10.0623
Gunnery Run P/U to the Right at 0.9 VL	3.6742	7.3485
Gunnery Run P/U (symmetrical) at 0.8 VL	.1522	5.0733
Normal Start/Shutdown (w/coll.)	3.9272	3.9272
Gunnery S-Turn at 0.8 VH	.7270	3.6352
Gunnery Run P/U to the Left at 0.8 VL	.9580	3.1934
Autorotation Landing	.7414	2.9777
Gunnery Run P/U to the Right at 0.8 VL	.8523	2.8409
Gunnery Turn to the Right at 0.9 VH	1.9089	2.5452
Gunnery Turn to the Left at 0.9 VH	1.5982	2.1309
Gunnery Run-Pt. Target Dive at VL	.5653	2.0188
Lateral Control Corr. at 0.9 VH	.0910	1.8191
Gunnery Run-Spray Fire Dive at VL	.2160	1.8001
Auto. to Power Transition at Max. Auto. A/S	.0286	1.1440
Hovering Longitudinal Control Corr. (IGL Maneuver)	.0107	1.0732
Rudder Control Corr. at 0.9 VH	.0435	.8692
Gunnery Run P/U (symmetrical) at 0.6 VL	.0082	.8179
Gunnery P/U to the Left at 0.6 VL	.0794	.7944
Gunnery Run P/U to the Right at 0.6 VL	.0718	.7184
Forward Level Flight VH at 314 RPM	.5478	.5478
Normal Left Turn at 0.9 VH	.9934	.4967
Gunnery Turn to the Left at 0.5 VH	.1675	.4465
Gunnery Turn to the Left at 0.7 VH	.1398	.3728
Gunnery Turn to the Right at 0.7 VH	.1361	.3630
Gunnery Turn to the Right at 0.5 VH	.1087	.2898
Gunnery Run-Spray Fire Dive at 0.9 VL	.1731	.2885
Quick Stop Deceleration (IGL Maneuver)	.0826	.2754
Approach and Landing (IGL Maneuve.)	.2285	.2285
High-Speed Full Power Climb	.1247	.1247
Forward Level Flight VH at 324 RPM	1.0412	.1157
Auto. to Power Transition at 0.6 VH	.0077	.1024
Auto. Turn to the Right at Max. Auto. A/S	.0040	.0809
Longitudinal Control Corr. at 0.9 VH	.0037	.0731
Gunnery Run-Pt. Target Dive at 0.9 VL	.0983	.0702
Gunnery Run-Spray Fire Dive at 0.8 VL	.0205	.0569
Normal Right Turn at 0.7 VH	.0384	.0384
Gunnery Run-Pt. Target Dive at 0.8 VL	.0271	.0322
Auto. Turn to the Left at Max. Auto. A/S	.0012	.0235
Normal Right Turn 0.9 VH	.0402	.0201
Hovering Lateral Control Corr. (IGL Maneuver)	.0001	.0088

Selection of Characteristic Parameters and Parameter Thresholds

References 4 and 5 were thoroughly searched for those flight parameters that have a consistent response to specific flight conditions. These documents contain pilot stick and pedal position data, component load data, and helicopter response data (such as roll rate, pitch rate, and pitch attitude). The documented flights, where each flight condition was flown many times in various gross weight-altitude combinations, were examined to detect the behavior of each recorded parameter during the defined flight conditions. (In describing the data reduction procedure, Reference 4 states that the maximum mean helicopter attitude and attitude rate values were measured and processed for each maneuver, but not for the level-flight flight conditions. The mean and oscillatory center-of-gravity vertical acceleration levels were measured and recorded at the maximum mean level for maneuvers and at the maximum oscillatory peak for the level-flight flight conditions.) The flight conditions that had ranked highly were examined very closely.

Each of the measurable flight parameters listed in Table 8 was considered individually or in combination with others to determine their potential in flight condition monitoring.

TABLE 8. CANDIDATE MONITORING PARAMETERS FOR FCM RECORDING SYSTEM

Vertical Acceleration @ c.g.	Pitch Attitude
Indicated Airspeed	Roll Attitude
Main Rotor Velocity	Pitch Rate
Landing Gear Touchdown	Roll Rate
Engine Torque Pressure	Yaw Rate

Table 9 shows sample data extracted from References 4 and 5 for two flight conditions: the gunnery run pullups to the right and left at V_L (V_L indicates limit velocity). These two flight conditions were ultimately considered sufficiently

4. Wettengel, W.O., MODEL AH-1G NONFIRING LOAD LEVEL SURVEY, VOLUMES I THROUGH IX, Report No. 209-099-041, Bell Helicopter Company, Fort Worth, Texas, June 1967.

5. Long, D.B., MODEL AH-1G HELICOPTER ARMAMENT QUALIFICATION TEST AND FIRING LOAD LEVEL SURVEY, Report No. 209-099-031, Bell Helicopter Company, Fort Worth, Texas, November 1967.

similar to be monitored as one flight condition category defined as follows:

Vertical Acceleration at c.g. $\geq$ 1.5g
Airspeed > 0.95 V_L
10° < Roll Attitude < 35°

TABLE 9. SAMPLE LOAD LEVEL SURVEY DATA

Flight Condition: Gunnery Run Pullup to the Right @ V_L

Origin of Data*	Vertical Acceleration @ c.g. (g)	Pitch Rate (deg/sec)	Roll Rate (deg/sec)	Yaw Rate (deg/sec)	Pitch Attitude (deg)	Roll Attitude (deg)
N_1	1.94	8	11	5	25	26
N_2	1.64	6	12	3	9	22
N_3	2.07	9	11	3	18	25
N_4	1.77	7	13	6	23	30
N_5	1.64	7	8	3	8	24
N_6	1.75	7	8	3	8	21
N_7	1.62	6	-3	4	-7	20
N_8	1.21	2	-2	2	-2	7
N_9	1.41	5	10	4	-7	23
N_{10}	1.63	7	13	3	15	25
F_1	2.01	11	18	5	6	26
F_2	2.16	11	17	5	-5	13
F_3	2.09	12	12	6	11	18
F_4	1.94	15	12	7	-5	13
F_5	1.75	11	18	2	1	16
F_6	1.82	10	17	0	1	13
F_7	1.72	8	17	4	-4	33
F_8	2.23	17	-2	8	12	34
F_9	1.82	7	-1	6	11	28
F_{10}	1.79	9	8	5	17	24

* NOTE:

N_i indicates data was taken from nonfiring load level survey

F_i indicates data was taken from firing load level survey

i indicates number of times flight condition was performed in load level survey

TABLE 9. Concluded

Flight Condition: Gunnery Run Pullup to the Left @ V_L

Origin of Data*	Vertical Acceleration @ c.g. (g)	Pitch Rate (deg/sec)	Roll Rate (deg/sec)	Yaw Rate (deg/sec)	Pitch Attitude (deg)	Roll Attitude (deg)
N_1	2.03	10	-9	-6	23	-35
N_2	1.73	8	-12	-5	9	-31
N_3	1.97	8	-14	-4	13	-33
N_4	1.78	8	-12	-4	21	-29
N_5	1.63	6	5	0	16	-21
N_6	1.66	4	11	-5	10	9
N_7	1.56	5	-7	-5	-12	-22
N_8	1.17	2	-4	-3	-5	-4
N_9	1.43	6	7	-4	8	-21
N_{10}	1.59	7	-15	-7	14	-31
F_1	2.19	12	-18	2	6	-24
F_2	2.20	11	-18	4	-6	-11
F_3	1.83	7	-5	-4	4	-9
F_4	1.85	9	-11	0	5	-13
F_5	1.86	10	-9	0	18	-10

* NOTE:

N_i indicates data was taken from nonfiring load level survey.

F_i indicates data was taken from firing load level survey.

i indicates number of times flight condition was performed in load level survey

In Table 2, where all airspeeds are expressed in terms of V_H (the maximum attainable level flight airspeed) or V_L (the limit airspeed), the V_H of 144 KTAS is defined in Reference 6, and V_L is defined in Reference 7 and shown in Figure 8. In

6. Finnestead, R.L., Laing, E., Connor, W.J., and Buss, M.W., ENGINEERING FLIGHT TEST, AH-1G HELICOPTER (HUEY/COBRA), PHASE D PART 2, PERFORMANCE, USAASTA 66-06, U.S. Army Aviation Systems Test Activity, Edwards Air Force Base, California, April 1970, AD 874210.

7. Technical Manual, TM 55-1520-221-10, OPERATOR'S MANUAL: ARMY MODEL AH-1G HELICOPTER, Headquarters, Department of the Army, Washington, D.C., 12 December 1975.

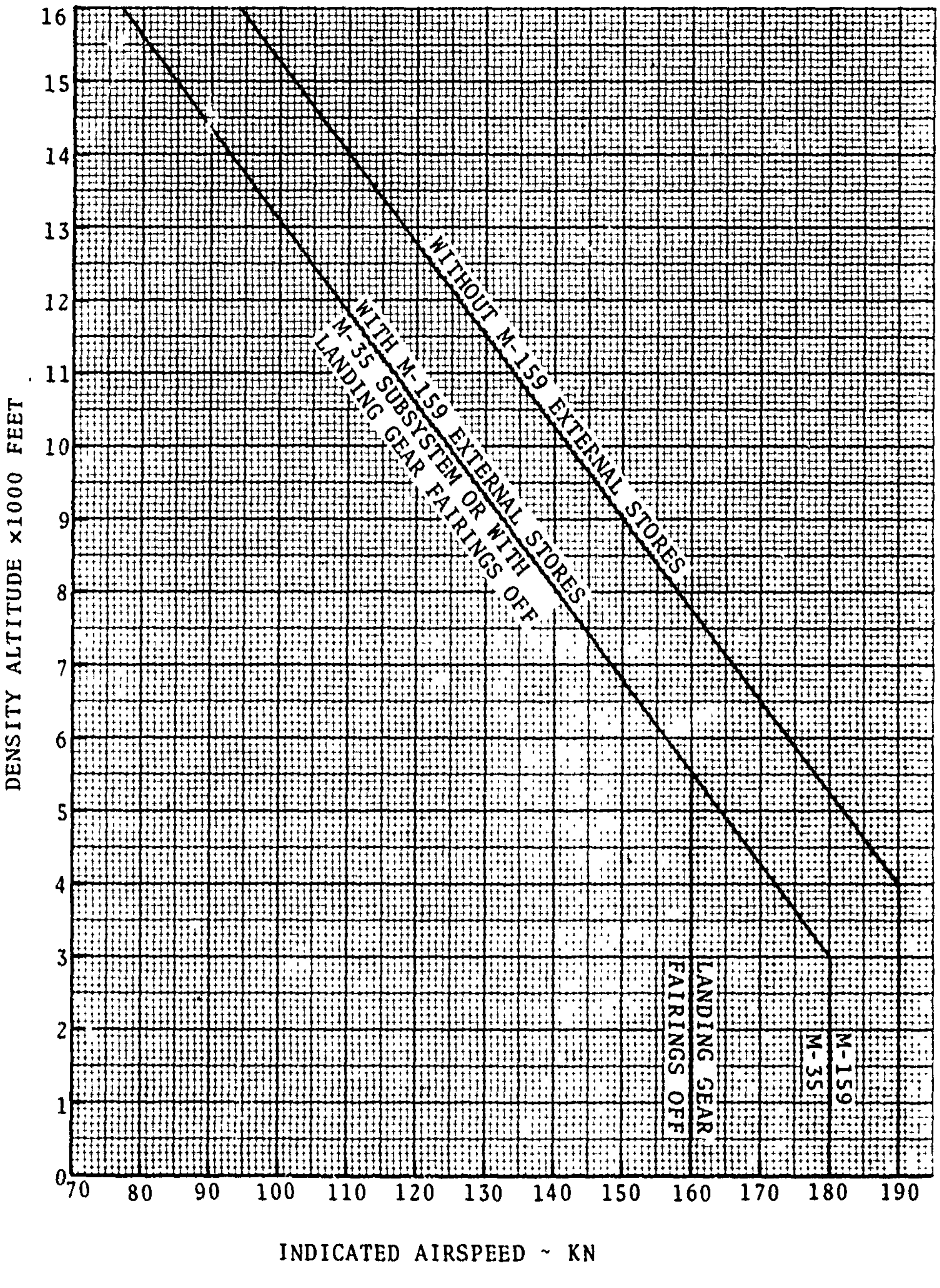


Figure 8. Limit Velocity (V_L) Definition.

this figure the airspeed limitation for the M-159 external stores configuration will be incorporated in the FCM system as a reasonable, although conservative, V_L definition. Since both V_H and V_L are a function of density altitude, pressure altitude and outside air temperature were included among the required parameters so that they could be monitored in conjunction with indicated airspeed. V_H and V_L can be calculated from the following equations:

$$V_H = 144 - \frac{H_d}{500} \tag{6}$$

and $$V_L = 180 \text{ knots below } H_d = 3000 \text{ ft} \tag{7}$$

$$V_L = 180 - 8 \left[\frac{H_d}{1000} - 3 \right] \text{ for } H_d \text{ above 3000 ft} \tag{8}$$

where V_H = maximum level flight airspeed, knots

V_L = limit airspeed, knots

H_d = density altitude, feet

the density altitude is calculated from:

$$H_d = 145{,}447 \left[1 - \left(\frac{9.6307\, P_a}{T + 273.18} \right)^{.235} \right] \tag{9}$$

where P_a = static pressure, inches mercury

T = outside air temperature, °C.

Since the damage rates for the AH-1G flight conditions vary significantly with gross weight, that parameter was included in the FCM system to further enhance the validity of the FCM system damage assessment model. The ranges chosen to represent the low, medium, and high gross weight categories are listed in Table 10.

TABLE 10. GROSS WEIGHT RANGES

Range Nomenclature	Gross Weight Range (lb)
L-GW	less than 7750
M-GW	7750 through 8750
H-GW	greater than 8750

The following method was chosen as the most practical means of reasonably estimating the instantaneous gross weight: (1) measure the takeoff gross weight by a landing skid deflection technique, and (2) conservatively estimate the instantaneous gross weight of the helicopter by only assuming that the gross weight linearly decreases with fuel burnoff.

Description of Recommended FCM System

The evaluation of all fatigue-damaging flight conditions relative to the previously described flight parameter behavior led to the selection of the parameters listed in Table 11 as the set of coordinated parameters which may best describe the

TABLE 11. SELECTED MONITORING PARAMETERS FOR FCM RECORDING SYSTEM

Directly Monitored Parameters	Symbol
Indicated Airspeed	A/S
Pressure Altitude	H_p
Outside Air Temperature	T
Main Rotor Velocity	MRV
Roll Attitude	β
Pitch Attitude	θ
Vertical Acceleration @ c.g.	n_z
Landing Gear Touchdown	TD
Engine Torque Pressure	ET
Takeoff Gross Weight	TGW

Computed Parameters	Symbol
Rate of Descent	RD
Maximum (Level Flight) Airspeed	V_H
Limit Airspeed	V_L
Instantaneous Gross Weight	GW

fatigue design spectrum in terms of a unique set of flight condition categories (FCC) (See Table 12). Although FCC 83 through 85, 89 through 91, and 95 through 97 do not specifically represent any of the flight conditions defined in the fatigue design spectrum, they enhance understanding of the AH-1G operational usage spectrum. (For example, FCC 96 was intended to measure and record the magnitude of the largest vertical acceleration peak during a recording period.) Table 12 summarizes the resultant FCM system recommended for the AH-1G helicopter. For simplicity, the breakdown of the 89 flight conditions by gross weight range was not shown in this table.

Note in Table 12 that it was necessary to formulate six flight condition categories that are not directly recorded (FCC 98 through 103). These FCC are reserved for estimations of time spent in making control corrections during hover and control corrections at 0.9 V_H. This provision was made because the data in Reference 4 revealed that although these flight conditions could not be confidently detected, their damage rates were of sufficient magnitude to warrant due recognition.

Therefore, since the control corrections occur on a statistical basis, it was decided to account for them by first defining the FCC in which their time would be included (the hovering control correction times would appear in FCC 1, 2, and 3, and the control correction times at 0.9 V_H would appear in FCC 14, 15, and 16). A liberal percentage of time (2 percent was chosen) was deducted from these recorded flight condition categories and assigned to FCC 98 through 103.

TABLE 12. FCM SYSTEM SUMMARY

Flt. Cond. Cat. No. L-GW	M-GW	H-GW	Flight Condition Category Description	Type Desig.[a]	Flight Conditions Included No.[b]	Description
1	2	3	Flight Clock Time	T	2	Normal Takeoff (IGE)
					3	Jump Takeoff (IGE)
					4	Steady Hover (IGE)
					5	Hovering Right Turn (IGE)
					6	Hovering Left Turn (IGE)
					10	Sideward Flight to the Right (IGE)
					11	Sideward Flight to the Left (IGE)
					12	Rearward Flight (IGE)
					13	Acceleration Hover to Climb A/S (IGE)
					14	Normal Deceleration (IGE)
					41	Sideslip
					43	Firing in a Hover
					44	Strafing in Acceleration from a Hover
	4		Rotor Start/Stop	C	1*	Normal Start/Shutdown (IGE)
5	6	7	Quick Stop	T	15*	Quick-Stop Deceleration (IGE)
8	9	10	Normal Landing	C	16*	Approach and Landing (IGE)
11	12	13	Low-Velocity Flight	T	17	Forward Level Flt. @ 0.50 V_H and 314 RPM
					18	Forward Level Flt. @ 0.50 V_H and 324 RPM
					19	Forward Level Flt. @ 0.60 V_H and 314 RPM
					20	Forward Level Flt. @ 0.60 V_H and 324 RPM
					29	Normal Full Power Climb
					32	Normal Right Turn @ 0.50 V_H
					35	Normal Left Turn @ 0.50 V_H
14	15	16	High-Velocity Flight	T	21	Forward Level Flt. @ 0.70 V_H and 314 RPM
					22	Forward Level Flt. @ 0.70 V_H and 324 RPM
					23	Forward Level Flt. @ 0.80 V_H and 314 RPM
					24	Forward Level Flt. @ 0.80 V_H and 324 RPM
					25	Forward Level Flt. @ 0.90 V_H and 314 RPM
					26	Forward Level Flt. @ 0.90 V_H and 324 RPM
					42	Part Power Descent
17	18	19	Maximum Velocity Flight	T	27*	Forward Level Flt. @ V_H and 314 RPM
					28*	Forward Level Flt. @ V_H and 324 RPM
20	21	22	High-Speed Full Power Climbs	T	30*	High-Speed Full Power Climbs
					31	Max. Rate Accel. Full Power Climb to Cruise A/S
23	24	25	Normal (High-Speed) Turns	T	33*	Normal Right Turn @ 0.70 V_H
					36	Normal Left Turn @ 0.70 V_H
26	27	28	Normal (High-Speed) Turns	T	34*	Normal Right Turn @ 0.90 V_H
					37	Normal Left Turn @ 0.90 V_H
29	30	31	Low-Velocity Dives	T	45	Gunnery Run Pt. Target Dive @ 0.60 V_L
					49	Gunnery Run-Spray Fire Dive @ 0.60 V_L
32	33	34	Moderate-Velocity Dives	T	46*	Gunnery Run-Pt. Target Dive @ 0.80 V_L
					50*	Gunnery Run-Spray Fire Dive @ 0.80 V_L
35	36	37	High-Velocity Dives	T	47*	Gunnery Run-Pt. Target Dive @ 0.90 V_L
					51*	Gunnery Run-Spray Fire Dive @ 0.90 V_L
38	39	40	Maximum-Velocity Dives	T	48*	Gunnery Run-Pt. Target Dive @ V_L
					52*	Gunnery Run-Spray Fire Dive @ V_L
41	42	43	Asymmetrical Pullups	T	53*	Gunnery Run P/U to the Right @ 0.60 V_L
					57*	Gunnery Run-P/U to the Left @ 0.60 V_L
44	45	46	Asymmetrical Pullups	T	54*	Gunnery Run-P/U to the Right @ 0.80 V_L
					58*	Gunnery Run-P/U to the Left @ 0.80 V_L
47	48	49	Asymmetrical Pullups	T	55*	Gunnery Run-P/U to the Right @ 0.90 V_L
					59*	Gunnery Run-P/U to the Left @ 0.90 V_L
50	51	52	Asymmetrical Pullups	T	56*	Gunnery Run-P/U to the Right @ V_L
					60*	Gunnery Run-P/U to the Left @ V_L

TABLE 12. Concluded

Flt. Cond. Cat. No. L-GW	M-GW	H-GW	Flight Condition Category Description	Type[a] Desig.	Flight Conditions Included No.[b]	Description
53	54	55	Symmetrical Pullups	T	61*	Gunnery Run-P/U (Symmetrical) @ 0.60 V_L
56	57	58	Symmetrical Pullups	T	62*	Gunnery Run-P/U (Symmetrical) @ 0.80 V_L
59	60	61	Symmetrical Pullups	T	63* 64*	Gunnery Run-P/U (Symmetrical) @ 0.90 V_L Gunnery Run-P/U (Symmetrical) @ V_L
62	63	64	Gunnery Turns	T	65* 68*	Gunnery Turn to the Right @ 0.50 V_H Gunnery Turn to the Left @ 0.50 V_H
65	66	67	Gunnery Turns	T	66* 69*	Gunnery Turn to the Right @ 0.70 V_H Gunnery Turn to the Left @ 0.70 V_H
68	69	70	Gunnery Turns	T	67* 70*	Gunnery Turn to the Right @ 0.90 V_H Gunnery Turn to the Left @ 0.90 V_H
71	72	73	High-Velocity S-Turn	T	71*	Gunnery S-Turn @ 0.80 V_H
74	75	76	Maximum-Velocity S-Turn	T	72*	Gunnery S-Turn @ V_H
77	78	79	Autorotation Clock Time	T	73 74 75 76 77 80 81 82 83 84 86 87	Power to Auto. Transition @ 0.50 V_H Power to Auto. Transition @ 0.70 V_H Power to Auto. Transition @ 0.90 V_H Auto. to Power Transition (IGL) Auto. to Power Transition @ 0.40 V_H Stabilized Auto. Flt. @ 0.40 V_H Stabilized Auto. Flt. @ 0.60 V_H Stabilized Auto. Flt. @ Max. Auto. A/S Auto. Turn to the Right @ 0.40 V_H Auto. Turn to the Right @ 0.60 V_H Auto. Turn to the Left @ 0.40 V_H Auto Turn to the Left @ 0.60 V_H
80	81	82	Auto. to Power Transition	C	78* 79*	Auto. to Power Transition @ 0.60 V_H Auto. to Power Trans. @ Max. Auto. A/S
83	84	85	Auto. to Power Transition	C	--	------------------------------------
86	87	88	High-Speed Auto. Turns	T	85* 88*	Auto. Turn to the Right @ Max. Auto. A/S Auto. Turn to the Left @ Max. Auto. A/S
89	90	91	High-Speed Auto. Turns	T	--	------------------------------------
92	93	94	Autorotation Landing	C	89*	Autorotation Landing
	95		Misc High-G Maneuvers	M	--	------------------------------------
	96		Maximum n_z Experienced	M	--	------------------------------------
	97		Maximum A/S Experienced	M	--	------------------------------------
98	99	100	Hovering Control Corrections	N	7* 8* 9	Hovering Longitudinal Control Corr. (IGE) Hovering Lateral Control Corr. (IGE) Hovering Rudder Control Corr. (IGE)
101	102	103	High-Speed Control Corr.	N	38* 39* 40*	Longitudinal Control Corr. @ 0.90 V_H Lateral Control Corr. @ 0.90 V_H Rudder Control Corr. @ 0.90 V_H

NOTE (a) T = category timer
C = category occurrence timer
M = maximum parameter magnitude attained
N = null recording category (control corrections times are conservatively estimated from other category timers)

NOTE (b) * Indicates Damaging Flight Conditions

DETERMINATION OF FCM SYSTEM TECHNICAL ACCEPTABILITY

The assessment of the technical acceptability of a candidate FCM system, such as the one described in Table 12, requires analyzing the proposed system with the aid of two computer programs, FCMMOD and SIMULE, which are documented in Reference 1.

Program FCMMOD uses the fatigue design spectrum and associated component damage rates, together with the FCM system definition, to compute appropriate fatigue-damage coefficients for each flight condition category. FCMMOD has a degree of built-in conservativeness since it increases the effect of the highly fatigue-damaging flight conditions in the derivation of flight condition category damage coefficients by simply assigning the maximum flight condition damage rate within each FCC as the damage coefficient for that category.

Program SIMULE simulates the operation of an FCM system by computing component fatigue lives from the FCMMOD-generated fatigue-damage coefficients in a given utilization spectrum, namely, the previously described mild and severe spectra in this application.

Fatigue-Damage Coefficients for FCM System

Table 13 presents the fatigue-damage coefficients for the FCM system described in Table 12. Any damage coefficient with a zero value indicates that the corresponding flight condition category is not fatigue-damaging for the particular component. Accordingly, since flight condition categories 95, 96, and 97 are not specifically representative of fatigue design spectrum flight conditions, their damage coefficients are zero.

Proposed FCM System Compliance with Technical Acceptance Criteria

For both the mild and the severe spectrum, Table 14 lists the SIMULE-computed fatigue lives for each of the 10 AH-1G components and the upper and lower fatigue life bounds for these components.

Since all fatigue lives fall within the respective bounds, the proposed FCM system and the associated FCM system damage model satisfy the technical acceptance criteria and therefore are valid means for assessing fatigue damage in AH-1G fatigue-critical components.

Detailed FCM System Description

Although the technically acceptable FCM system described in Table 12 defines the system parameter combinations and associated threshold levels, it does not define a completely workable system. For example, consider flight condition

TABLE 13. FATIGUE DAMAGE COEFFICIENTS FOR EACH COMPONENT IN EACH FLIGHT CONDITION CATEGORY

Flight Condition Category	Main Rotor Blade	Main Rotor Yoke Extension	Main Rotor Grip	Main Rotor Pitch Horn	Retention Strap Ftg./Nut
1	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	.3623E-01
5	0.	0.	0.	0.	0.
6	.4267E-03	0.	0.	0.	0.
7	.1789E-02	0.	0.	0.	0.
8	0.	0.	0.	0.	0.
9	.8420E-03	0.	0.	0.	0.
10	.6800E-03	0.	0.	0.	0.
11	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.
17	.4245E-02	0.	0.	0.	0.
18	.2900E-03	0.	0.	0.	0.
19	.2867E-03	0.	0.	0.	0.
20	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.
22	.1137E-02	0.	0.	0.	0.
23	0.	0.	0.	0.	0.
24	.2100E-03	0.	0.	0.	0.
25	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.
28	.1833E-03	0.	0.	0.	0.
29	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.
34	.5185E-03	0.	0.	0.	0.
35	.2917E-03	0.	0.	0.	0.
36	.2700E-03	0.	0.	0.	0.
37	.1094E-02	0.	0.	0.	0.
38	.4482E-02	0.	0.	0.	0.
39	.1429E-03	0.	0.	0.	0.
40	.6778E-02	0.	0.	0.	0.
41	0.	0.	0.	0.	0.
42	.8200E-03	0.	0.	0.	0.
43	.3700E-02	0.	0.	.6233E-02	0.
44	.2867E-02	0.	0.	.1167E-02	0.
45	.4193E-02	0.	0.	.1400E-02	0.
46	.5567E-02	0.	0.	.9478E-02	0.
47	.1440E-02	.2970E-02	0.	.7500E-03	0.
48	.5904E-02	.7080E-02	0.	.3156E-02	0.
49	.1717E-01	.5107E-02	0.	.1499E-01	0.
50	.3900E-01	.1250E-01	0.	.2400E-02	0.
51	.1640E-01	.2366E-01	0.	.4840E-02	0.
52	.5860E-01	.2437E-01	0.	.2223E-01	0.

TABLE 13. Continued

Flight Condition Category	Main Rotor Blade	Main Rotor Yoke Extension	Main Rotor Grip	Main Rotor Pitch Horn	Retention Strap Ftg./Nut
53	0.	0.	0.	0.	0.
54	.8000E-03	0.	0.	0.	0.
55	.3667E-02	0.	0.	.6333E-02	0.
56	.6667E-03	0.	0.	.3333E-03	0.
57	.5600E-02	0.	0.	.1120E-01	0.
58	.1244E-01	.1044E-01	0.	.1933E-01	0.
59	.1085E+00	.1400E-01	0.	.1050E-01	0.
60	.7780E-01	.1140E-01	0.	.1700E-01	0.
61	.1173E+00	.1153E-01	0.	.3733E-01	0.
62	0.	0.	0.	0.	0.
63	.3467E-03	0.	0.	0.	0.
64	.4053E-02	0.	0.	0.	0.
65	.5333E-03	0.	0.	0.	0.
66	.6880E-03	0.	0.	0.	0.
67	.2267E-02	0.	0.	.3644E-03	0.
68	.4080E-02	0.	0.	0.	0.
69	.7445E-02	0.	0.	.4560E-03	0.
70	.6489E-02	0.	0.	.1204E-02	0.
71	.2900E-02	.9050E-02	0.	0.	0.
72	.5100E-02	0.	0.	0.	0.
73	.1123E-01	0.	0.	0.	0.
74	.1773E-01	.2133E-01	0.	0.	0.
75	.9921E-02	.3605E-02	0.	0.	0.
76	.1245E-01	.1705E-01	.4786E-01	0.	0.
77	0.	0.	0.	0.	0.
78	0.	0.	0.	0.	0.
79	.2511E-02	0.	0.	0.	0.
80	.4000E-03	0.	0.	0.	0.
81	.1600E-03	0.	0.	0.	0.
82	.8667E-02	0.	0.	0.	0.
83	.4000E-03	0.	0.	0.	0.
84	.1600E-03	0.	0.	0.	0.
85	.8667E-02	0.	0.	0.	0.
86	0.	0.	0.	0.	0.
87	0.	0.	0.	0.	0.
88	0.	0.	0.	0.	0.
89	0.	0.	0.	0.	0.
90	0.	0.	0.	0.	0.
91	0.	0.	0.	0.	0.
92	.1114E-01	0.	0.	0.	0.
93	.5320E-02	0.	0.	0.	0.
94	.3947E-02	.1005E-01	0.	0.	0.
95	0.	0.	0.	0.	0.
96	0.	0.	0.	0.	0.
97	0.	0.	0.	0.	0.
98	.8000E-02	0.	0.	0.	0.
99	.1400E-02	0.	0.	0.	0.
100	.1000E-02	0.	0.	0.	0.
101	.8100E-02	0.	0.	0.	0.
102	.1140E-01	0.	0.	0.	0.
103	.5867E-02	0.	0.	0.	0.

TABLE 13. Continued

Flight Condition Category	Swashplate Drive Link	Swashplate Outer Ring	Swashplate Inner Ring	Hydraulic Boost Cylinder	Tail Rotor Blade
1	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.
17	0.	0.	.4450E-03	0.	0.
18	0.	0.	0.	0.	.5340E-03
19	0.	0.	0.	0.	.7467E-03
20	0.	0.	[illegible]	0.	0.
21	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	.2592E-02
28	0.	0.	0.	0.	.4800E-03
29	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	.5667E-03
37	0.	0.	.3952E-03	0.	0.
38	0.	0.	.5893E-03	0.	0.
39	0.	0.	.1657E-02	.2214E-03	.1707E-02
40	0.	.2024E-02	.7655E-02	.1155E-02	.7278E-02
41	0.	0.	0.	0.	0.
42	0.	0.	0.	0.	0.
43	.1567E-02	.1043E-01	.4000E-03	.1500E-02	0.
44	0.	.1067E-02	0.	.1017E-02	.1000E-02
45	.3727E-02	.4087E-02	.2953E-02	.2893E-02	.5067E-03
46	.3222E-02	.1052E-01	.8744E-02	.1322E-01	.5889E-02
47	.1830E-02	.7600E-02	.5640E-02	.3410E-02	.3107E-01
48	.9200E-03	.4536E-02	.3784E-02	.1265E-01	.9344E-02
49	.5420E-02	.4553E-02	.5353E-02	.4299E-01	.1360E-01
50	.4000E-03	.1350E-02	.1300E-02	.1460E-01	.1830E-01
51	.1022E-01	.3400E-02	.3220E-02	.3312E-01	.1916E-01
52	.2693E-01	.6267E-02	.8733E-02	.7277E-01	.3733E-01

TABLE 13. Concluded

Flight Condition Category	Swashplate Drive Link	Swashplate Outer Ring	Swashplate Inner Ring	Hydraulic Boost Cylinder	Tail Rotor Blade
53	0.	0.	0.	0.	0.
54	0.	0.	0.	0.	0.
55	.1667E-02	0.	.6667E-03	.1367E-01	0.
56	0.	0.	0.	.1667E-02	.1167E-02
57	.3267E-02	.6667E-03	.2000E-02	.4867E-02	.1333E-02
58	.6333E-02	.4333E-02	.6667E-02	.1456E-01	.3556E-02
59	.3000E-02	.1000E-02	.2000E-02	.1400E-01	.1000E-01
60	.7800E-02	.1400E-02	.2720E-02	.2040E-01	.7000E-02
61	.1400E-01	.9600E-02	.6333E-02	.3800E-01	.1680E-01
62	0.	0.	0.	0.	0.
63	0.	0.	0.	0.	0.
64	0.	0.	0.	.6844E-03	0.
65	0.	0.	0.	0.	0.
66	0.	0.	0.	.1600E-04	0.
67	0.	0.	0.	0.	0.
68	0.	.2880E-02	.1487E-02	0.	.3327E-02
69	.1453E-02	.2560E-03	0.	.3413E-03	.3840E-03
70	.3289E-03	.5040E-02	.5244E-02	.9556E-03	.6324E-02
71	0.	.2250E-03	.2175E-02	0.	.5750E-03
72	0.	0.	0.	.2000E-04	.2740E-02
73	0.	.1583E-02	.3917E-02	0.	.8333E-03
74	0.	.2600E-02	.4133E-02	.4000E-03	.1667E-01
75	0.	.4737E-03	.2763E-02	.3421E-03	.1866E-01
76	0.	.2273E-02	.1055E-01	0.	.6377E-01
77	0.	0.	0.	0.	0.
78	0.	0.	0.	0.	0.
79	0.	0.	0.	0.	0.
80	0.	0.	0.	0.	0.
81	0.	0.	0.	0.	0.
82	0.	.1200E-02	.8000E-03	0.	.6667E-03
83	0.	0.	0.	0.	0.
84	0.	0.	0.	0.	0.
85	0.	.1200E-02	.8000E-03	0.	.6667E-03
86	0.	0.	0.	0.	0.
87	0.	0.	0.	0.	0.
88	0.	.8000E-03	0.	0.	.5333E-03
89	0.	0.	0.	0.	0.
90	0.	0.	0.	0.	0.
91	0.	.8000E-03	0.	0.	.5333E-03
92	0.	0.	0.	0.	0.
93	0.	0.	0.	0.	0.
94	0.	0.	0.	0.	.5733E-03
95	0.	0.	0.	0.	0.
96	0.	0.	0.	0.	0.
97	0.	0.	0.	0.	0.
98	0.	0.	0.	.1000E-02	0.
99	0.	0.	0.	.5600E-02	0.
100	0.	0.	0.	0.	0.
101	0.	.4000E-03	0.	0.	.1260E-01
102	0.	0.	0.	0.	0.
103	0.	0.	0.	0.	.4667E-03

TABLE 14. TECHNICAL ACCEPTABILITY RESULTS

Component Identification	FCM System Performance Assessed Damage	FCM System Performance Projected Life	Fatigue Life Bounds Lower	Fatigue Life Bounds Upper
Mild Utilization Spectrum				
Main Rotor Blade	.324574E-01	3,081	1,100	4,307
Main Rotor Yoke Extension	.493331E-02	20,271	3,300	24,917
Main Rotor Grip	.526500E-03	189,934	Unlimited	190,042
Main Rotor Pitch Horn	.681070E-02	14,683	6,600	17,953
M/R Retention Strap Ftg./Nut	.105077E-01	9,517	2,200	9,517
Swashplate Drive Link	.458481E-02	21,812	11,000	27,353
Swashplate Outer Ring	.723471E-02	13,823	3,300	18,707
Swashplate Inner Ring	.573742E-02	17,430	3,300	25,128
Hydraulic Boost Cylinder	.161467E-01	6,134	3,300	8,635
Tail Rotor Blade	.118041E-01	8,472	1,100	12,106
Severe Utilization Spectrum				
Main Rotor Blade	.400355E-01	2,498	1,100	3,542
Main Rotor Yoke Extension	.843841E-02	11,851	3,300	14,779
Main Rotor Grip	.143591E-02	69,643	Unlimited	69,686
Main Rotor Pitch Horn	.112521E-01	8,888	6,600	10,596
M/R Retention Strap Ftg./Nut	.223197E-01	4,481	2,200	4,488
Swashplate Drive Link	.747809E-02	13,373	11,000	16,513
Swashplate Outer Ring	.110711E-01	9,033	3,300	12,325
Swashplate Inner Ring	.925062E-02	10,811	3,300	15,481
Hydraulic Boost Cylinder	.233981E-01	4,274	3,300	5,145
Tail Rotor Blade	.190302E-01	5,255	1,100	7,192

categories 50, 51, and 52, which represent high-speed asymmetrical gunnery run pullups. Although these maneuvers are identified by the combination of a vertical acceleration above 1.5g, a roll attitude between 10° and 35°, and an airspeed greater than 0.95 V_L, they are not adequately represented by simply measuring the time within which the parameters are attaining the foregoing values simultaneously. Rather, these maneuvers would likely be better represented by the time duration of the roll attitude while it exceeded and returned to 10° but did not reach 35°, provided that the airspeed is above 0.95 V_L at the initial 10° crossing and that the vertical acceleration exceeds 1.5g within a prescribed time after the initial 10° crossing.

Various considerations, such as the reasoning in the foregoing example, led to the definition of a much more detailed FCM system. Because of the lengthy description needed to define each flight condition category in the resultant FCM system, these flight condition categories are depicted and defined in Appendix A.

Because of the complexity of many of the flight condition categories and the parameter monitoring requirements, the FCM

recorder incorporates a microprocessor. During the development of the FCM system, the airborne recorder was flight-tested with an oscillograph recorder capable of monitoring those parameters listed in Table 8. Then the two sets of data were compared to evaluate the functioning of the FCM recorder and to adjust the parameter threshold levels in the FCM system so that the established flight conditions could be better defined.

CHAPTER 3.

SYSTEM DESCRIPTION

The SIRS system consists of three discrete but interrelated subsystems. The airborne SIRS recorder monitors helicopter usage by identifying and storing the occurrences of various flight conditions. The ground-based, portable data retrieval unit transfers the recorder-stored data onto a miniature data tape cassette on a monthly basis. At a central data processing site, the software system automatically processes and analyzes the data, and then generates tailored reports that present the usage and corresponding incremental fatigue damage to each component for each monitored helicopter. The complete system is pictured in Figure 9.

SIRS RECORDER

The SIRS recorder, viewed in Figure 10, incorporates a Motorola Model 6800 microprocessor. This microprocessor monitors the nine flight parameters listed in Table 15 and from them calculates the density altitude and adjusted airspeed limits.

When these flight parameters fall in preset ranges or form certain flight conditions, the microprocessor accumulates their occurrences or the amount of time associated with them in the recorder's data-storage memory. The flight conditions are defined generally as various combinations of flight parameters, each in a preset range. Examples of flight conditions are flight time, rotor starts, and maximum vertical acceleration. Table 16 lists the 22 flight condition categories established for the AH-1G.

As shown in Figure 11, the SIRS recorder processes the inputs from the transducers for the nine monitored parameters. Each of the inputs is conditioned to a desired full-scale signal level, multiplexed, and converted from an analog to a digital signal to be processed by the microprocessor. The recorder software logic identifies the flight conditions by associating the variation and corresponding time of each input parameter with those of the other input parameters. While these conditions are being identified, the microprocessor calculates the density altitude and limit velocities and temporarily stores the calculations in the recorder's scratch pad memory. The programs for these calculations and the flight condition software logic are contained in EPROM (erasable programmable read-only memory) integrated circuits. The time spent in or the number of occurrences of the various flight conditions is stored in the recorder's data-storage memory, which consists of RAM (random access memory) integrated circuits. Since these circuits are volatile, the recorder

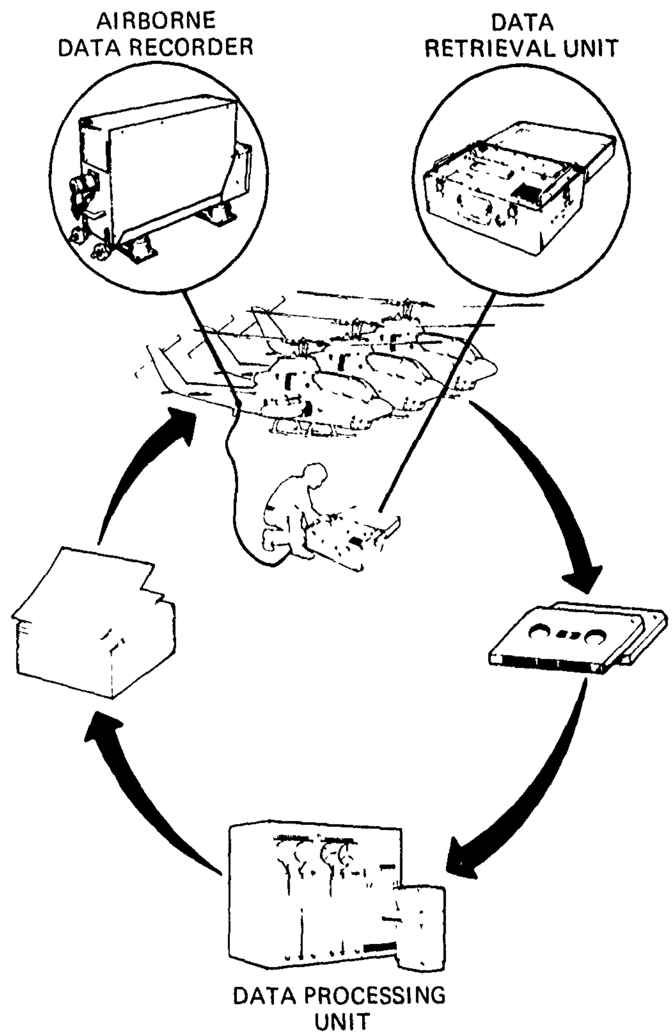


Figure 9. Structural Integrity Recording System.

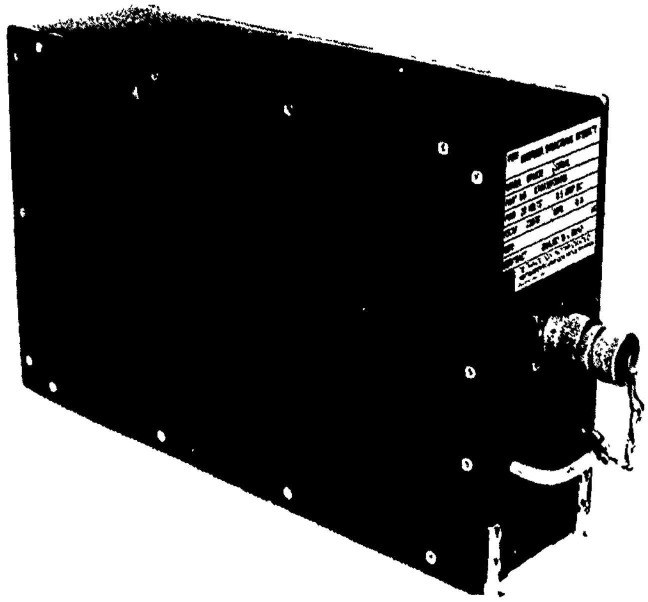


Figure 10. SIRS Recorder.

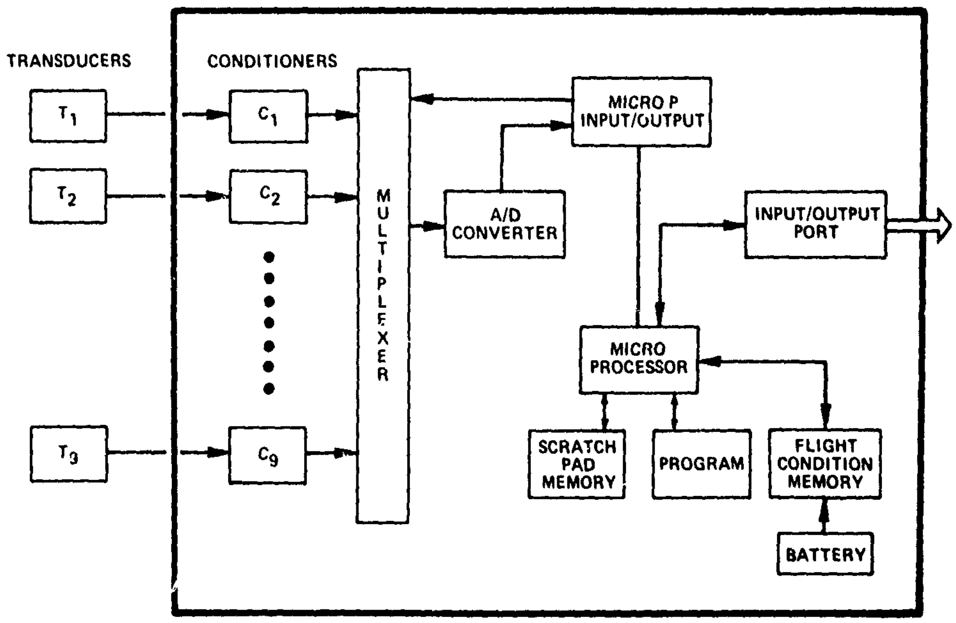


Figure 11. Schematic of Structural Integrity Recorder.

TABLE 15. SIRS PARAMETERS

Measured	Computed
Airspeed	Percent V_L Airspeed
Pressure Altitude	Percent V_H Airspeed
Outside Air Temperature	Density Altitude
Gross Weight	
Pitch Attitude	
Roll Attitude	
Engine Torque	
Main Rotor Speed	
Vertical Acceleration	
Touchdown	

TABLE 16. FLIGHT CONDITION CATEGORIES

Title	Measured Quantity		
	Occurrences	Time	Measured Value
Flight Time		*	
Rotor Start/Stop	*		
Full Power Climb		*	
Low-Speed Flight		*	
High-Speed Flight		*	
Maximum-Speed Flight		*	
Normal High-Speed Turns		*	
Gunnery Turns		*	
Gunnery S-Turns		*	
Gunnery Run Dives-Symmetrical		*	
-Asymmetrical		*	
Symmetrical Pullouts		*	
Asymmetrical Pullouts		*	
High n_z Maneuvers	*		
Normal Landings	*		
Autorotation Time		*	
Autorotation Turns		*	
Autorotation to Power Transition	*		
Autorotation Landings	*		
Quick-Stop Deceleration		*	
Maximum % V_L			*
Maximum n_z			*

incorporates dual batteries with a one-year operational capacity to retain the stored data when aircraft power is turned off. The recorder software package is listed in Appendix B.

The recorder installation, including recorder, shock mount, transducers, and harnesses, weighs 20.3 pounds; a detailed breakdown of the installation's weight is presented in Table 17. The recorder, including mounting rack and electromagnetic-interference-shielded connector, is 17.50 inches long, 6.50 inches wide, and 10.15 inches high; these dimensions include the necessary space for recorder/shock mount sway. The recorder operates on 28 Vdc supplied by the aircraft and consumes approximately 7 watts.

RETRIEVAL UNIT

SIRS is designed so that data need be retrieved only once a month by the portable, flight-line data retrieval unit pictured in Figure 12. During the transcription of the recorder data onto the miniature magnetic tape cassette, the operator interacts with the unit. While the unit displays messages, the operator communicates with the unit through a keyboard. Because of the on-board processing of the flight data, the data recorded during the normal monthly operation of more than 50 helicopters can be stored on a single data cassette. The program used to permit retrieval unit and recorder interactions is called the Initial Processing System (IPS). The data retrieval, including setup, takes less than 5 minutes and can be performed on a flexible schedule. In addition to data retrieval, the data retrieval unit performs diagnostic checks of the recorder, on-board recorder battery, and transducers. It can also be used as a readout device during the transducer calibrations.

During the retrieval process, limited operator inputs listed in Table 18 are requested to supplement data contained within the recorder. The aircraft serial number is entered in the format of fiscal year and aircraft number, xx-xxxxx, and supplements the recorder serial number, which is permanently stored electronically within the recorder. Since retrievals are not performed on a fixed schedule, the retrieval data, in the format of day, month, and year, is another entry; this information is used to indicate trends in the retrieval data. The chronology of the data is identified by a numbering device built into the recorder that increments each time a retrieval is made. Logbook flight hours are entered to track the variation between the actual flight and ground-operating time and the logged time. The operating base is entered to permit analyzing the fleet-wide variation in helicopter usage. Finally, as requested by the display, the operator enters the reason for the data retrieval. There are three acceptable reasons: monthly retrieval, component replacement, and re-

TABLE 17. SIRS RECORDER WEIGHT BREAKDOWN

Component	Weight (lb)
Recorder/Rack	9.25
Airspeed/Altitude Transducer and Brackets	1.6
OAT	0.07
Vertical Acceleration Transducer and Bracket	1.2
Gross Weight Transducer and Bracket	0.14
Harnesses and misc. hardware	8.0
Total	20.26

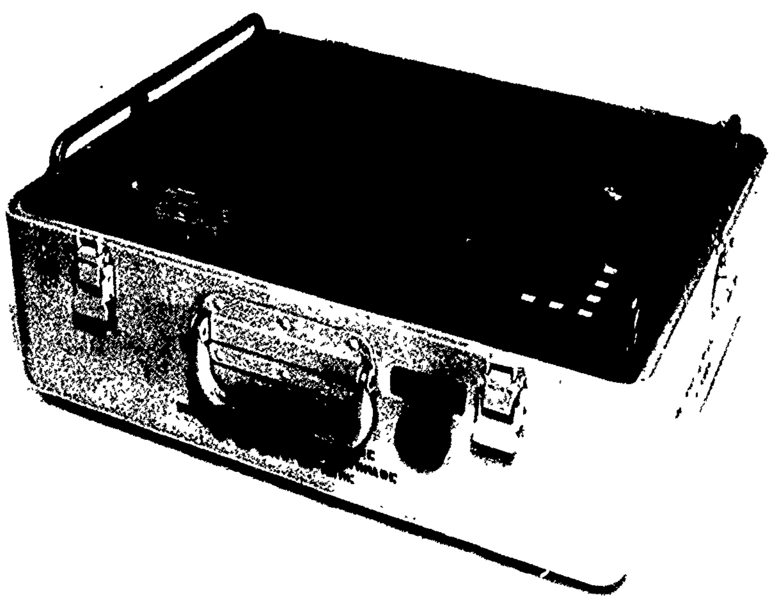


Figure 12. SIRS Retrieval Unit.

corder maintenance. After the operator enters the supplemental data, the data retrieval unit performs a diagnostic check of the recorder including its memory, makes a copy of the recorder data residing in memory, and records the current static values of each of the transducers. These data, together with the supplemental data previously entered by the operator, are recorded on the miniature magnetic tape cassettes. Each time the data is transferred, that is, from the memory in the recorder to that in the data retrieval unit and from the latter to the cassette, it is checked to verify the validity of the transfer.

TABLE 18. SIRS RETRIEVAL UNIT OPERATOR INPUTS

Aircraft Serial Number	Base of Operation
Date of Retrieval	Reason for Retrieval
Log Book Flight Hours	

The various error messages listed in Table 19 are displayed when the diagnostic check detects recorder deficiencies, when data cannot be retrieved or written on the tape cassette, or when the tape cassette is not installed or is full. Each coded error message (instructions for each are mounted inside the cover of the data retrieval unit) leads the operator to the necessary corrective action.

The data retrieval unit is 19.1 inches long, 15.6 inches wide, and 9.8 inches high and weighs 45.4 pounds. The retrieval unit has a rechargeable power system and is housed in a flight-line styled container. The recharging power required is 110 to 120 Vac, 60 Hz.

SOFTWARE

Upon receiving the data from the miniature cassettes, the software system first performs an initial data processing to (1) verify the recorder operation and transducer functioning and (2) to review the long-term trend of the transducer static readings, and then analyzes the data. The analysis includes the data segregation by specific flight condition categories, the data conversion to a 100-flight-hour basis, and the data presentation in terms of a usage spectrum. An example of this data presentation is shown in Figure 13. Next the software system governs three techniques to further analyze the data by calculating the incremental fatigue damage for each critical tracked component. The first technique is based on the relationship of the recorder data with the SIRS fatigue model developed for the AH-1G helicopter. In the second technique the calculations are based on the rates established by current Army-approved component replacement times and the logbook flight hours. The third technique is the same as the second

SIRS SPECTRUM USAGE

AIRCRAFT: 66-15254 LOG TIME: 1985.6 RETRIEVAL DATE: 50477 REASON: SCHEDULED
RECORDER: 1030 BASE: 1
DELTA LOG TIME: 1.0 HOURS
VALUES PER 100 HOURS WERE COMPUTED USING THE RETRIEVAL TIME.

FLIGHT CONDITION	GROSS WEIGHT (LB)	TIME (HOURS) RETRIEVAL	PER 100 HOURS	OCCURRENCE RETRIEVAL	PER 100 HOURS
FLIGHT TIME	TOTAL	0.9	100.0		
1	<7750	0.5	56.9		
2	7750-8750	0.4	43.1		
3	>8750	0.0	0.0		
ROTOR CYCLES	TOTAL			1	113.8
4				1	113.8
QUICK STOPS	TOTAL	0.0	0.0		
5	<7750	0.0	0.0		
6	7750-8750	0.0	0.0		
7	>8750	0.0	0.0		
NORMAL LDGS	TOTAL			1	113.8
8	<7750			1	113.8
9	7750-8750			0	0.0
10	>8750			0	0.0
LOW SPEED FLT	TOTAL	0.0	4.3		
11	<7750	0.0	0.4		
12	7750-8750	0.0	3.9		
13	>8750	0.0	0.0		
HIGH SPEED FLT	TOTAL	0.5	52.6		
14	<7750	0.3	29.5		
15	7750-8750	0.2	23.1		
16	>8750	0.0	0.0		
MAX SPEED FLT	TOTAL	0.0	3.7		
17	<7750	0.0	1.7		
18	7750-8750	0.0	2.0		
19	>8750	0.0	0.0		
HIGH TORQUE FLT	TOTAL	0.0	0.0		
20	<7750	0.0	0.0		
21	7750-8750	0.0	0.0		
22	>8750	0.0	0.0		
LOW SPEED TURNS	TOTAL	0.0	0.0		
23	<7750	0.0	0.0		
24	7750-8750	0.0	0.0		
25	>8750	0.0	0.0		

Figure 13. Sample of Spectrum Generated by SIRS Software.

SIRS SPECTRUM USAGE

AIRCRAFT: 66-15254 LOG TIME: 1985.6 RETRIEVAL DATE: 50477 REASON: SCHEDULED
RECORDER: 1030 BASE: 1
DELTA LOG TIME: 1.0 HOURS
VALUES PER 100 HOURS WERE COMPUTED USING THE RETRIEVAL TIME.

FLIGHT CONDITION	GROSS WEIGHT (LB)	TIME (HOURS) RETRIEVAL	PER 100 HOURS	OCCURRENCE RETRIEVAL	PER 100 HOURS
HIGH SPEED TURNS	TOTAL	0.1	8.3		
26	<7750	0.1	7.0		
27	7750-8750	0.0	1.2		
28	>8750	0.0	0.0		
LOW SPEED DIVES	TOTAL	0.0	0.0		
29	<7750	0.0	0.0		
30	7750-8750	0.0	0.0		
31	>8750	0.0	0.0		
MED SPEED DIVES	TOTAL	0.0	0.3		
32	<7750	0.0	0.2		
33	7750-8750	0.0	0.2		
34	>8750	0.0	0.0		
HIGH SPEED DIVES	TOTAL	0.0	0.1		
35	<7750	0.0	0.0		
36	7750-8750	0.0	0.1		
37	>8750	0.0	0.0		
MAX SPEED DIVES	TOTAL	0.0	0.0		
38	<7750	0.0	0.0		
39	7750-8750	0.0	0.0		
40	>8750	0.0	0.0		
LOW SPD ASYM P/U	TOTAL	0.0	0.0		
41	<7750	0.0	0.0		
42	7750-8750	0.0	0.0		
43	>8750	0.0	0.0		
MED SPD ASYM P/U	TOTAL	0.0	0.0		
44	<7750	0.0	0.0		
45	7750-8750	0.0	0.0		
46	>8750	0.0	0.0		
HI SPD ASYM P/U	TOTAL	0.0	0.0		
47	<7750	0.0	0.0		
48	7750-8750	0.0	0.0		
49	>8750	0.0	0.0		
MAX SPD ASYM P/U	TOTAL	0.0	0.0		
50	<7750	0.0	0.0		
51	7750-8750	0.0	0.0		
52	>8750	0.0	0.0		

Figure 13. Continued

SIRS SPECTRUM USAGE

AIRCRAFT: 66-15254 LOG TIME: 1985.6 RETRIEVAL DATE: 50477 REASON: SCHEDULED
RECORDER: 1030 BASE: 1
DELTA LOG TIME: 1.0 HOURS
VALUES PER 100 HOURS WERE COMPUTED USING THE RETRIEVAL TIME.

FLIGHT CONDITION	GROSS WEIGHT (LB)	TIME (HOURS) RETRIEVAL	TIME (HOURS) PER 100 HOURS	OCCURRENCE RETRIEVAL	OCCURRENCE PER 100 HOURS
LOW SPD SYM P/U	TOTAL	0.0	0.0		
53	<7750	0.0	0.0		
54	7750-8750	0.0	0.0		
55	>8750	0.0	0.0		
MED SPD SYM P/U	TOTAL	0.0	0.0		
56	<7750	0.0	0.0		
57	7750-8750	0.0	0.0		
58	>8750	0.0	0.0		
HIGH SPD SYM P/U	TOTAL	0.0	0.0		
59	<7750	0.0	0.0		
60	7750-8750	0.0	0.0		
61	>8750	0.0	0.0		
LOW SPD GUN TURN	TOTAL	0.0	0.0		
62	<7750	0.0	0.0		
63	7750-8750	0.0	0.0		
64	>8750	0.0	0.0		
MED SPD GUN TURN	TOTAL	0.0	0.0		
65	<7750	0.0	0.0		
66	7750-8750	0.0	0.0		
67	>8750	0.0	0.0		
HI SPD GUN TURN	TOTAL	0.1	5.9		
68	<7750	0.0	0.8		
69	7750-8750	0.0	5.1		
70	>8750	0.0	0.0		
GUN S-TURN	TOTAL	0.0	4.4		
71	<7750	0.0	4.4		
72	7750-8750	0.0	0.0		
73	>8750	0.0	0.0		
MAX SPD S-TURN	TOTAL	0.0	0.0		
74	<7750	0.0	0.0		
75	7750-8750	0.0	0.0		
76	>8750	0.0	0.0		
AUTO TIME	TOTAL	0.0	2.1		
77	<7750	0.0	2.1		
76	7750-8750	0.0	0.0		
79	>8750	0.0	0.0		

Figure 13. Continued

SIRS SPECTRUM USAGE

AIRCRAFT: 66-15254 LOG TIME: 1985.6 RETRIEVAL DATE: 50477 REASON: SCHEDULED
RECORDER: 1030 BASE: 1
DELTA LOG TIME: 1.0 HOURS
VALUES PER 100 HOURS WERE COMPUTED USING THE RETRIEVAL TIME.

FLIGHT CONDITION	GROSS WEIGHT (LB)	TIME (HOURS) RETRIEVAL	PER 100 HOURS	OCCURRENCE RETRIEVAL	PER 100 HOURS
LOW NZ AUTO/PWR	TOTAL			0	0.0
80	<7750			0	0.0
81	7750-8750			0	0.0
82	>8750			0	0.0
HIGH NZ AUTO/PWR	TOTAL			0	0.0
83	<7750			0	0.0
84	7750-8750			0	0.0
85	>8750			0	0.0
LOW NZ AUTO TURN	TOTAL	0.0	0.0		
86	<7750	0.0	0.0		
87	7750-8750	0.0	0.0		
88	>8750	0.0	0.0		
HI NZ AUTO TURN	TOTAL	0.0	0.0		
89	<7750	0.0	0.0		
90	7750-8750	0.0	0.0		
91	>8750	0.0	0.0		
AUTO LOGS	TOTAL			0	0.0
92	<7750			0	0.0
93	7750-8750			0	0.0
94	>8750			0	0.0

95	HIGH NZ COUNTER	12
96	MAX NZ VALUE	2.4
97	MAX A/S VALUE	1.0

Figure 13. Concluded

except that the recorder flight time is used instead of the logbook flight time. Figure 14 is a sample of the format used in presenting the data calculated by each technique. The software package permitting these calculations is called the Fatigue Damage Assessment System (FDAS).

TABLE 19. RETRIEVAL UNIT ERROR MESSAGES

LINE ABORT?	-	Denotes that the retrieval unit-to-recorder communications were not properly established or were interrupted.
DATA ABORT?	-	Denotes that there was an error condition during the transmission of the recorder data onto the retrieval unit's temporary data-storage memory.
WRITE ABORT?	-	Denotes that there was an error condition during the data writing on the magnetic tape.
FULL ABORT?	-	Denotes that sufficient space could not be found on the magnetic tape for the data writing.
TAPE ABORT?	-	Denotes that the tape cassette is not capable of reading or writing because of its malfunctioning or improper positioning.
COUNTER	-	Denotes that a bad memory location was detected during the diagnostic check of the recorder's data storage memory.
BATTERY	-	Denotes that the recorder's battery power supply is marginal.

Software Concept

The data processing and management system is composed of three parts: the Initial Processing System (IPS), the Fatigue Damage Assessment System (FDAS), and the Component Tracking Management System (CTMS). Each of the three modules of the system was treated and designed as a separate entity. This allows for ease of maintenance of the system and flexibility in the operation of the system.

COMPONENT DAMAGE

AIRCRAFT: 66-15254 LOG TIME: 1985.6 RETRIEVAL DATE: 50477 REASON: SCHEDULED
RECORDER: 1030 BASE: 1
DELTA LOG TIME: 1.0 HOURS
DELTA RECORDER TIME: 0.9 HOURS

COMPONENT	SIRS DAMAGE	FLIGHT HOUR DAMAGE RECORDER	LOG
MAIN ROTOR BLADE	0.00072	0.00080	0.00091
MAIN ROTOR YOKE EXTENSION	0.00035	0.00027	0.00030
MAIN ROTOR GRIP	0.0	0.00009	0.00010
MAIN ROTOR PITCH HORN	0.00002	0.00013	0.00015
RETENTION STRAP FTG/NUT	0.00009	0.00040	0.00045
SWASHPLATE DRIVE LINK	0.00007	0.00008	0.00009
SWASHPLATE OUTER RING	0.00004	0.00027	0.00030
SWASHPLATE INNER RING	0.00010	0.00027	0.00030
HYDRAULIC BOOST CYLINDER	0.00010	0.00027	0.00030
TAIL ROTOR BLADE	0.00017	0.00080	0.00091

Figure 14. Sample of Component Damage Generated by SIRS Software.

The first two modules, IPS and FDAS, were written in FORTRAN in accordance with contract requirements, but the CTMS was written in COBOL. This was done to maintain a uniformity with the data management techniques being employed by the AVRADCOM computer center. This was in the best interest of the Government, since AVRADCOM is postulated as the eventual user of the system and the development was to be performed on AVRADCOM equipment.

The development was to take place by utilizing a Remote Job Entry terminal located at Technology Incorporated and connected to the AVRADCOM computer via a dial-up communication link.

The following paragraphs briefly describe the main functions of the three modules, and Figures 15, 16, and 17 present system flow.

IPS. The Initial Processing System checks for proper operation of the recorder, the recording medium, and the retrieval unit. This is performed in a number of ways; initially, the IPS checks the parity of the data and the results of the built-in test. The data from the individual counters are then tested for validity to assure that they are within reasonable tolerances.

If the data or any part thereof are determined to be invalid, conservative estimates based on past usage and engineering judgment are made for the erroneous data.

The valid data and/or the estimated data from the various counters are then written on an output tape and identified as actual or estimated for further processing. A printout identifying any equipment problems is also prepared for submittal to the appropriate activity.

FDAS. The Fatigue Damage Assessment System takes each of the forwarded counter values and assigns a damage value to each component according to the model established for the monitored aircraft type. The actual and estimated incremental damages are kept separate for each component.

A data tape is then written and forwarded for further processing. This tape contains the actual or estimated incremental damage for each component type, identified by aircraft serial number. The date of the data is also forwarded.

CTMS. The Component Tracking Management System is the main data management module of the overall system. Its primary function is to update and maintain two tracking files and to generate data reports for field and management usage.

The programs take the data passed on from the FDAS and check the date, in case of removal, to determine with which components the data is associated. The appropriate component's damage fraction is then updated, still retaining the identity of the actual and estimated parts.

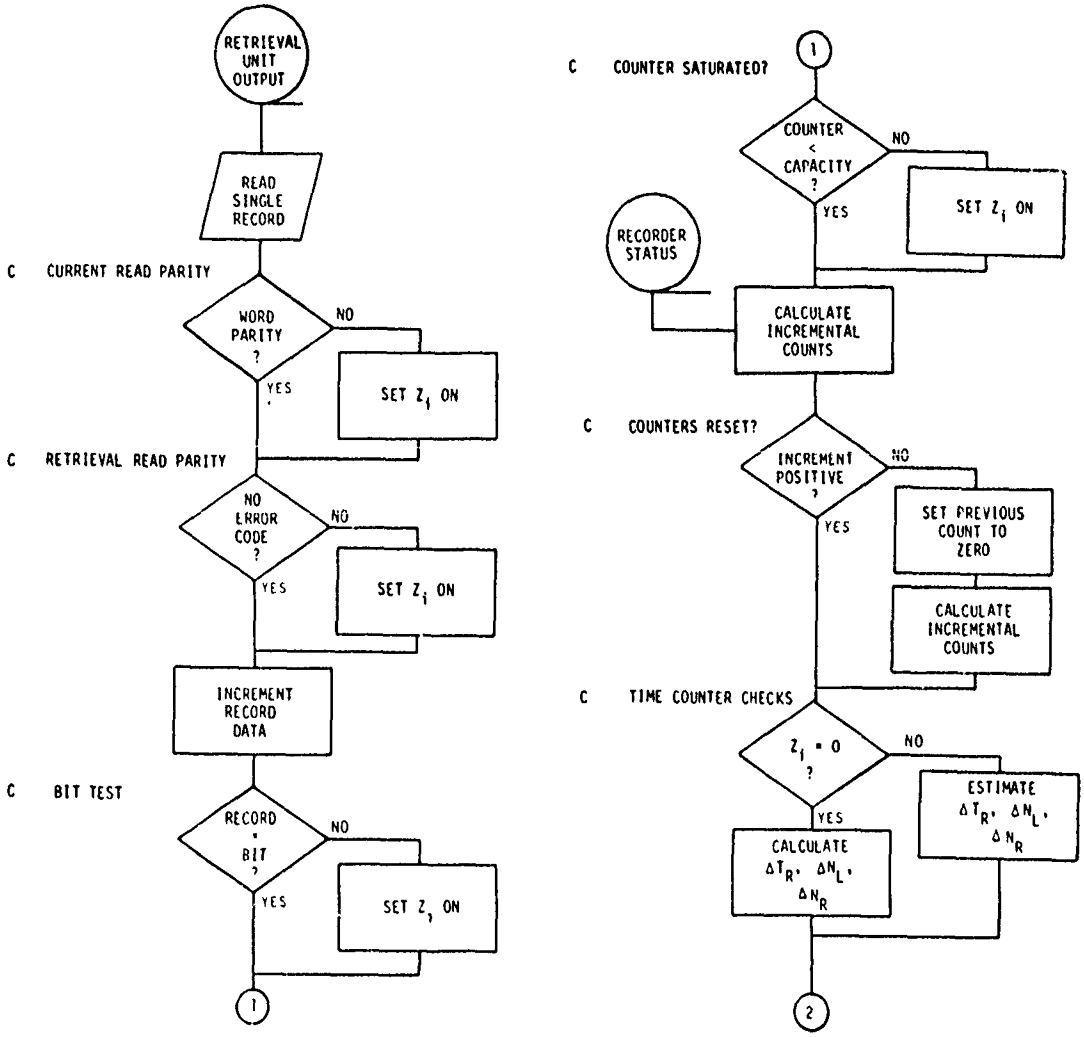


Figure 15. Flow Chart of IPS Processing.

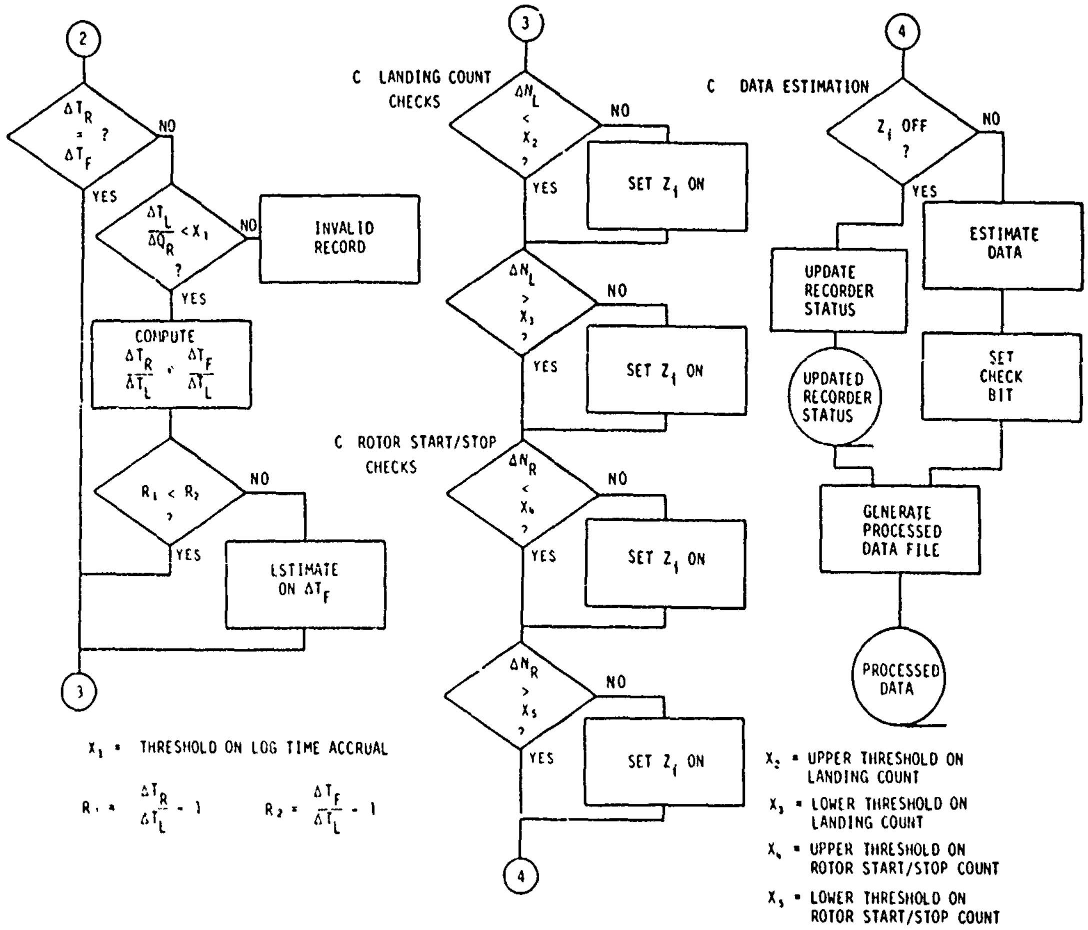


Figure 15. Concluded

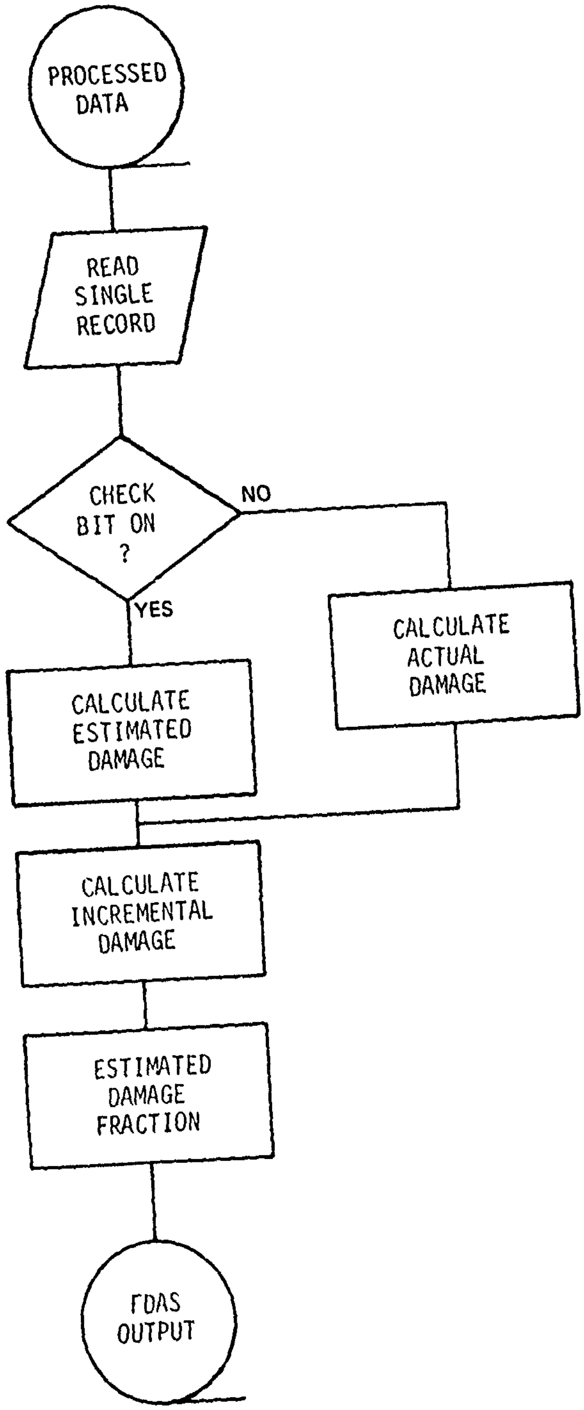


Figure 16. Flow Chart of FDAS Processing.

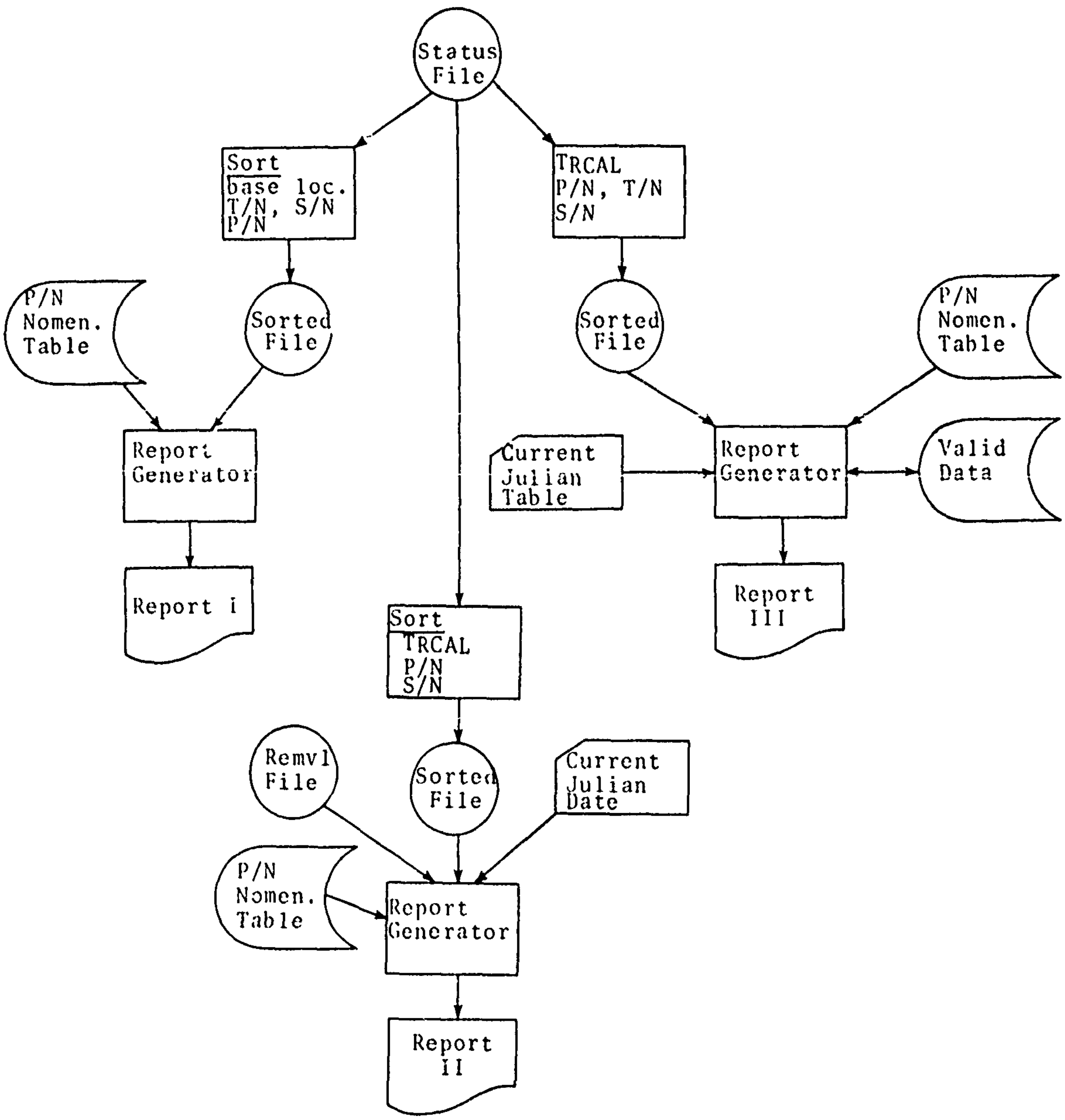


Figure 17. Report Generation Processing.

The status file is then updated with the new damage fractions. The status file contains the historical information concerning each aircraft. This includes the configuration of each aircraft and the time and damage fraction associated with each fatigue-critical component. It is from this file that the majority of the data reports are generated.

A secondary file, the removal file, is maintained for all removed components. This file is used to provide statistical information on removals and to track components removed for overhaul or for other reasons.

It is from these files that the various data reports are generated. Figures 18, 19, and 20 give samples of the reports that will be presented. The reports deal with status of the various components once a certain damage fraction is attained, life projections over selected periods of time, and component replacements due or overdue. The reports will be used for maintenance, management, and planning.

Supplemental Data. In the event of component removals, a supplemental update form (Figure 21) will be completed. This data will be entered into the FDAS to ensure the proper accountability and tracking of the various components.

INSTALLATION KIT

The SIRS recording system was married to the AH-1G airframe via an installation kit consisting of miscellaneous structural hardware, cabling, and specialized instruments. All of the mounting systems were designed to withstand crash loads. This discussion focuses on the sensor suite providing the inputs to the recorder.

The remote sensors required to obtain the data are grouped into the following four categories:

- Pressure transducers
- Accelerometers
- Position potentiometers
- Miscellaneous sensors

Pressure Transducers

The pressure transducers are capacitive type, providing a 0-5 Vdc output signal. For airspeed, a differential pressure transducer that senses the difference between the pitot and static pressures is used. For altitude, an absolute pressure transducer senses the aircraft static pressure.

Accelerometers

The transducer used to sense the normal (vertical) acceleration is a servo force balance type providing a 0-5 Vdc output signal.

SELECTED COMPONENT STATUS
DAMAGE FRACTION GREATER THAN 0.7

A/C TYPE/MODEL: CH-47C
AIRCRAFT NO: 64-13145
BASE: FT RUCKER
DATA THRU: 05/01/74
REPORT DATE: 05/15/74

COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	COMPONENT SERIAL NUMBER	DAMAGE ACCRUAL RATE		DAMAGE FRACTION	PERCENTAGE OF DAMAGE FRACTION ESTIMATED	REMAINING LIFE (HRS)	REPLACEMENT DATE JULIAN DATE	
114R2196-2	PIN HORIZONTAL HINGE	PL593	.00034	P	0.971	3.2	0	74130	***
114R1543-4	BLADE SOCKET ROTOR HUB	7-5669-1	.00063	P	0.891	4.1	94	74176	*
114R2155	TIE BAR AFT ROTOR HUB	W-411-0	.00056	S	0.733	0.9	388	74330	
114R1502-33	ROTOR BLADE, AFT	5988413	.00074	T	0.784	2.7	224	74217	*
114R1543-3	BLADE SOCKET, FWD HUB	67-33921	.00042	P	0.716	1.4	557	75053	
114D3250	AFT ROTOR SHAFT	SL-4119N	.00055	T	0.711	3.2	435	74348	

*** THIS MAJOR COMPONENT HAS REACHED OR EXCEEDED 0.95 DAMAGE AND REPLACEMENT IS OVERDUE

* THIS MAJOR COMPONENT IS DUE FOR REPLACEMENT IN 0-3 MONTHS

P - DAMAGE ACCRUAL RATE BASED ON DATA FROM THE PREVIOUS MONTH

S - DAMAGE ACCRUAL RATE BASED ON DATA FROM THE PREVIOUS 6 MONTHS

T - DAMAGE ACCRUAL RATE BASED ON TOTAL PREVIOUS DATA

Figure 18. Report I, Selected Component Status.

SELECTED COMPONENT
USEFUL LIFE PROJECTIONS

A/C TYPE: CH-47C
BASE: FT RUCKER
DATA PERIOD: JAN-MAR 1974
REPORT DATE: 05/15/74

COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	REMOVALS LAST QUARTER	PROJECTED REMOVALS FOR 0-3 MONTHS	PROJECTED REMOVALS FOR 0-12 MONTHS	PROJECTED REMOVALS FOR 12-15 MONTHS	PROJECTED REMOVALS FOR 12-24 MONTHS
114R2050	HEAD ASSY (HUB),ROTARY	13	20	87	39	186
114R2196-2	PIN HORIZONTAL HINGE	54	63	274	110	572
114R2088	PITCH SHAFT AFT ROTOR	49	58	289	131	593
114R1543-4	BLADE SOCKET AFT ROTOR	79	50	265	99	509
114R2155	TIE BAR AFT ROTOR HUB	58	56	256	147	388
114R1502-33	AFT ROTOR BLADE	53	61	269	125	587
114D3250	AFT ROTOR SHAFT	18	22	90	41	202
114R2197	PITCH SHAFT FWD HUB	56	62	257	115	568
114R2155	TIE BAR FWD ROTOR HUB	56	53	263	122	611
114R1543-3	BLADE SOCKET FWD HUB	59	60	272	143	556

Figure 19. Report II, Selected Component Removal Projections.

A/C TYPE/MODEL: CH-47C
DATA PERIOD: MAY-JULY 1974
REPORT DATE: 05/15/74

REPLACEMENTS DUE 0-3 MONTHS

COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	COMPONENT SERIAL NUMBER	A/C NO.	BASE	REMOVAL DATE
114R2088	PITCH SHAFT AFT ROTOR	M5421	68-43110	FT RUC	05/30/74
114R2088	PITCH SHAFT AFT ROTOR	C4701	67-55462	FT RUC	06/15/74
114R1543-4	BLADE SOCKET AFT ROTOR	VY1022	67-22629	FT RUC	05/30/74
114R2196-2	PIN HORIZONTAL HINGE	A510	68-43110	FT RUC	06/03/74
114R2196-2	PIN HORIZONTAL HINGE	VY4149	67-55462	FT RUC	07/28/74
114R2155	TIE BAR AFT ROTOR HUB	PL248-14	68-43110	FT RUC	06/17/74
114R2155	TIE BAR AFT ROTOR HUB	A1244	67-22629	FT RUC	07/09/74
114R2155	TIE BAR FWD ROTOR HUB	VF0110	67-55462	FT RUC	07/13/74
114R1502-33	AFT ROTOR BLADE	A913	67-55462	FT RUC	06/23/74
114R1502-33	AFT ROTOR BLADE	A84277	68-43110	FT RUC	07/14/74
114R2197	PITCH SHAFT FWD HUB	NL11740	67-22629	FT RUC	07/05/74
114R1543-3	BLADE SOCKET FWD HUB	VEZ0112	67-55462	FT RUC	07/15/74

Figure 20. Report III, Replacements Due in 0-3 Months, by Component Number.

REPLACEMENTS DUE 0-3 MONTHS

A/C TYPE/MODEL: CH-47C
DATA PERIOD: MAY-JULY 1974
REPORT DATE: 05/15/74

A/C NUMBER	BASE	COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	COMPONENT SERIAL NUMBER	REMOVAL DATE
67-22629	FT RUC	114R1543-4	BLADE SOCKET AFT ROTOR	VY1022	05/30/74
67-22629	FT RUC	114R2197	PITCH SHAFT FWD HUB	NL11740	07/05/74
67-22629	FT RUC	114R2155	TIE BAR AFT ROTOR HUB	A1244	07/09/74
67-55462	FT RUC	114R2088	PITCH SHAFT AFT ROTOR	C4701	06/15/74
67-55462	FT RUC	114R1502-33	AFT ROTOR BLADE	A913	06/23/74
67-55462	FT RUC	114R2196-2	PIN HORIZONTAL HINGE	VY4149	07/28/74
67-55462	FT RUC	114R2155	TIE BAR FWD ROTOR HUB	VE0110	07/13/74
67-55462	FT RUC	114R1543-3	BLADE SOCKET FWD HUB	VEZ0112	07/15/74
68-43110	FT RUC	114R2088	PITCH SHAFT AFT ROTOR	M5421	05/30/74
68-43110	FT RUC	114R2196-2	PIN HORIZONTAL HINGE	A510	06/03/74
68-43110	FT RUC	114R2155	TIE BAR AFT ROTOR HUB	PL248-14	06/17/74
68-43110	FT RUC	114R1502-33	AFT ROTOR BLADE	A84277	07/14/74

Figure 20. Continued

A/C TYPE/MODEL: CH-47C
REPORT DATE: 05/15/74

OVERDUE REPLACEMENTS

COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	COMPONENT SERIAL NUMBER	A/C NO.	BASE	REMOVAL DATE
114D3250	AFT ROTOR SHAFT	55-3104	67-22629	FT RUC	01/03/74
114D3250	AFT ROTOR SHAFT	T6299	68-43110	FT RUC	04/23/74
114D3250	AFT ROTOR SHAFT	R2327	67-55462	FT RUC	05/01/74
114R2088	PITCH SHAFT AFT ROTOR	VZ10043	65-10143	FT RUC	03/03/74
114R2089	PITCH SHAFT AFT ROTOR	L439218	67-22629	FT RUC	03/28/74
114R2050	HEAD ASSY (HUB), ROTARY	EX124	66-05372	FT RUC	03/18/74
114R1502-33	AFT ROTOR BLADE	4-316-9	66-05372	FT RUC	04/10/74
114R1502-33	AFT ROTOR BLADE	4438	67-22629	FT RUC	05/01/74
114R2155	TIE BAR FWD ROTOR HUB	LB431	65-10143	FT RUC	04/11/74
114R2155	TIE BAR FWD ROTOR HUB	A6464	66-05372	FT RUC	04/30/74
114R2196-2	PIN HORIZONTAL HINGE	VA4335	65-10143	FT RUC	04/23/74
114R2197	PIN HORIZONTAL HINGE	JU52038	66-05372	FT RUC	05/02/74

Figure 20. Continued

OVERDUE REPLACEMENTS

A/C TYPE/MODEL: CH-47C
REPORT DATE: 05/15/74

A/C NUMBER	BASE	COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	COMPONENT SERIAL NUMBER	REMOVAL DATE
65-10143	FT RUC	114R2088	PITCH SHAFT AFT ROTOR	VZ10043	03/03/74
65-10143	FT RUC	114R2155	TIE BAR FWD ROTOR HUB	LB431	04/11/74
65-10143	FT RUC	114R2196-2	PIN HORIZONTAL HINGE	VA4335	04/23/74
66-05372	FT RUC	114R2050	HEAD ASSY (HUB),ROTARY	EX124	03/18/74
66-05372	FT RUC	114R1502-33	AFT ROTOR BLADE	4-316-9	04/10/74
66-05372	FT RUC	114R2155	TIE BAR FWD ROTOR HUB	A6464	04/30/74
66-05372	FT RUC	114D3250	AFT ROTOR SHAFT	R2327	05/01/74
66-05372	FT RUC	114R2197	PIN HORIZONTAL HINGE	JU52038	05/02/74
67-22629	FT RUC	114D3250	AFT ROTOR SHAFT	S5-3104	01/03/74
67-22629	FT RUC	114R2088	PITCH SHAFT AFT ROTOR	L439218	03/28/74
67-22629	FT RUC	114R1502-33	AFT ROTOR BLADE	4338	05/01/74
68-43110	FT RUC	114D3250	AFT ROTOR SHAFT	T6299	04/23/74

Figure 20. Concluded

U.S. ARMY CRITICAL PARTS MANAGEMENT PROGRAM
FATIGUE-CRITICAL COMPONENT REPLACEMENT FORM

BASE:			A/C TAIL NO.			A/C TYPE/MODEL	
REPLACEMENTS ACCOMPLISHED			REASON REMOVED (X)				
A/C HOURS	MO/DAY/YEAR	MECHANIC	TIME EXPIRED	FAILED	PRE-CAUTION	MOD	SERVICE
			1	2	3	4	5

COMPONENT REMOVALS

REMOVED PART P/N ____________________ S/N ____________________

INSTALLED PART P/N ____________________ S/N ____________________

TSN: ____________________ TSO: ____________________

REMARKS:

Figure 21. Update Form for Component Removals.

Flight Control Positions

To sense rudder pedal position, an infinite resolution potentiometer is used. This unit is wired such that the potentiometer acts as two arms of a Wheatstone bridge circuit. Connected by special actuators to the control linkage, this potentiometer senses the movement of the respective control system. The mechanical attachments between the potentiometer and the control linkages are designed so that binding of the mechanisms will cause them to fail; hence, control of the helicopter cannot b inhibited by the instrumentation system.

Miscellaneous Sensors

Several parameters either require sensing the aircraft's flight instruments or cannot be placed in one of the above categories. The following paragraphs discuss these sensors.

Outside Air Temperature. The outside air temperature is monitored with a thermal ribbon. The ribbon is attached to, but insulated from, the outer skin of the aircraft. The ribbon is a resistor whose resistance varies with the temperature and is used as the active arm of a Wheatstone bridge circuit.

Rotor Speed. To monitor the main rotor rpm, a special circuit was designed and fabricated. The circuit is composed of all solid-state materials and is mounted on a printed circuit board within the signal conditioning section of the recorder. The output of the counter controls a gate which varies a +5 Vdc circuit between +5 Vdc and ground. The resultant voltage is filtered and reduced to a pure dc signal acceptable to the recorder.

Engine Torque. Engine torque data is acquired from the aircraft's torque transmitter by utilizing a differential amplifier input circuit for isolation and a converter to condition the torque signal. The initial signal is a fixed-frequency, varying amplitude, engine torque signal that is converted to an appropriate dc signal. Variations in this signal due to changes in the torque reference are nullified by monitoring the reference and having the recorder perform a division.

Roll and Pitch Attitudes. Attitude data is obtained from the roll and pitch outputs of the aircraft's attitude gyro. This interface uses solid-state, modular, synchro-to-dc converters with the reference and synchro inputs fully isolated to prevent any degradation of the aircraft's attitude indicator system.

Gross Weight (GW) Indicator. The parameters to compute the gross weight of the helicopter were originally measured prior to each takeoff by two Kistler Morse Model DMC-3-FF-4-1-03 piezoelectric beam sensors attached to the midpoint of the fore-and-aft crosstube members of the skid landing gear. While the helicopter was on the ground the rotor speed was less than 250 rpm, the SIRS recorder processed the sensor outputs to yield the gross weight. An algorithm incorporated in the recorder decreased the gross weight value as fuel was burned. No adjustment was made for the decrease in gross weight due to stores or ammunition dispensing. When this procedure was found inadequate, another approach was used.

The second GW sensor system involved bonding strain gauges to the lift links' transmission mounting members. This was intended to give positive, real-time GW data.

Power and Signal Interconnections

A system wiring harness includes all wiring between the recorder, remote sensors, and aircraft power. The 28 Vdc is acquired by installing circuit breakers in the pilot's right-hand breaker panel and connecting to the nonessential dc bus.

CHAPTER 4.

TEST PROGRAM

A test program was conducted to evaluate the concept of flight condition recording as a means of collecting usage spectrum data. The test program consisted of five elements.

- Brassboard Evaluation
- Laboratory Qualification Testing
- Reliability Analysis
- Prototype Flight Test
- Usage Spectrum Data Collection

Brassboard Evaluation

From the outset, critical elements of SIRS were identified for early testing. The final product was quite close to the original conception.

On-Board Recorder. The recorder circuit can be functionally divided into two primary sections, analog and digital. The analog section consisted of a reference voltage source, individual circuits for each input parameter, and the A/D multiplexer. The digital section consisted of the processor system (CPU, memory, serial and parallel I/O ports), a timing circuit, address decoding, power fail-restart, and an aircraft power-to-battery switchover circuit.

Analog circuits for engine torque, temperature, roll attitude, the reference voltage, and A/D multiplexer circuits were provided. The circuit for the main rotor rpm is presented in Figure 22. The circuit for the outside air temperature measurement is presented in Figure 23. Figures 24 and 25 depict circuits used for various buffered circuits.

Preliminary tests of the digital section of the recorder provided FCC counter data to be stored in one MC5-101L-4 CMOS memory chip. Although satisfactory for the 36 flight condition categories presently defined, the possibility that gross weight considerations could double this number led to the suggestion that the digital printed circuit board layout should allow for the addition of a second memory chip. The brassboard configuration was modified to include the additional memory. Laboratory tests confirmed this to be satisfactory.

The flight recorder case size was to conform to Drive 404, 3/8 airborne transmitter rack. The case was constructed of 19-gauge (0.042") 0.1018 cold-drawn steel.

The finish applied to all steel parts was according to QQ-P-416 Type 2, Class 2 (chromium and chromate plating). All parts internal to the flight recorder with the exception of the power filter were mounted on the PC boards. The power

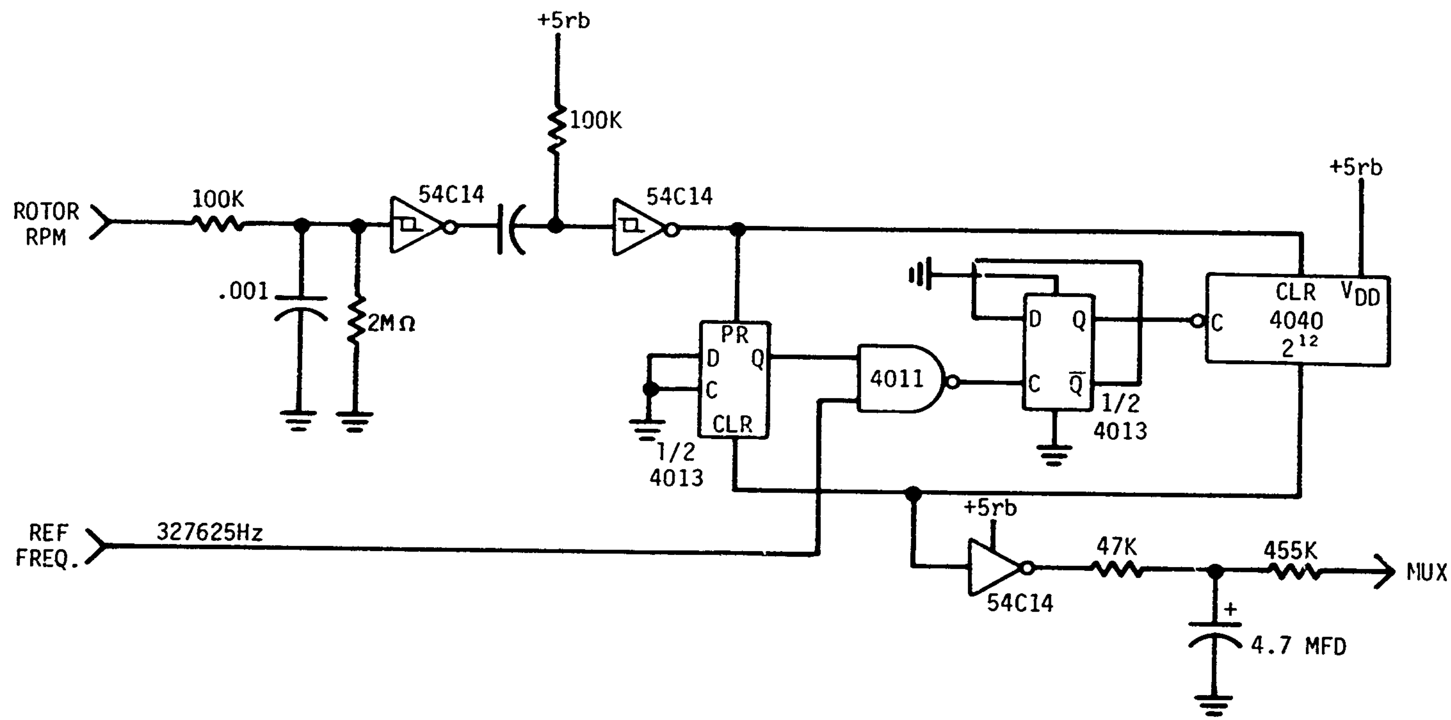
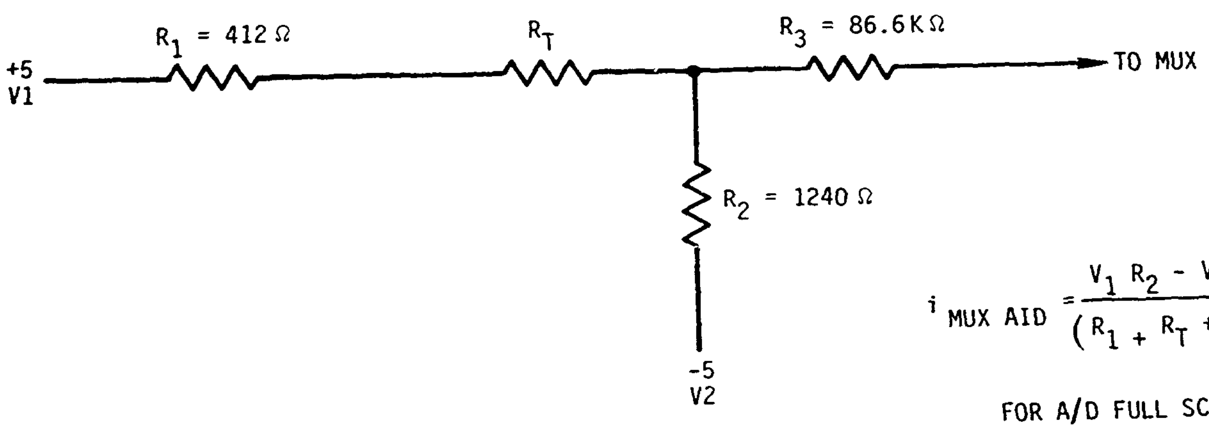


Figure 22. Rotor RPM Measurement.



$$i_{\text{MUX AID}} = \frac{V_1 R_2 - V_2(R_1 + R_T)}{(R_1 + R_T + R_2)(R_2 + R_3) - R_2^2}$$

FOR A/D FULL SCALE = 10 μ AMPS

$$\text{A/D OUT} = i_{\text{MUX AID}} \times 100{,}000 \times 256$$

$$\text{A/D OUT} = i \times 25{,}600{,}000$$

FOR $R_1 = 412$, $R_2 = 1240$, $R_3 = 86.6K$

$V_1 = V_2 = 5.000$ VDC

$$\text{A/D OUT} = \frac{256\,(828 - R_T)}{.17568\,R_T + 287.14816}$$

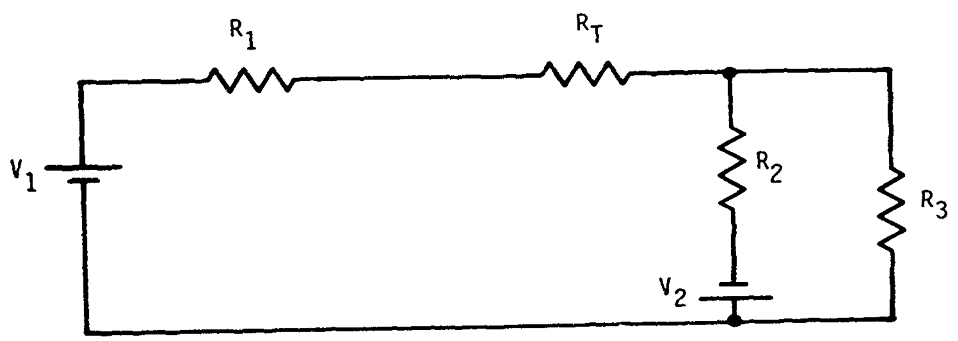


Figure 23. OAT Measurement.

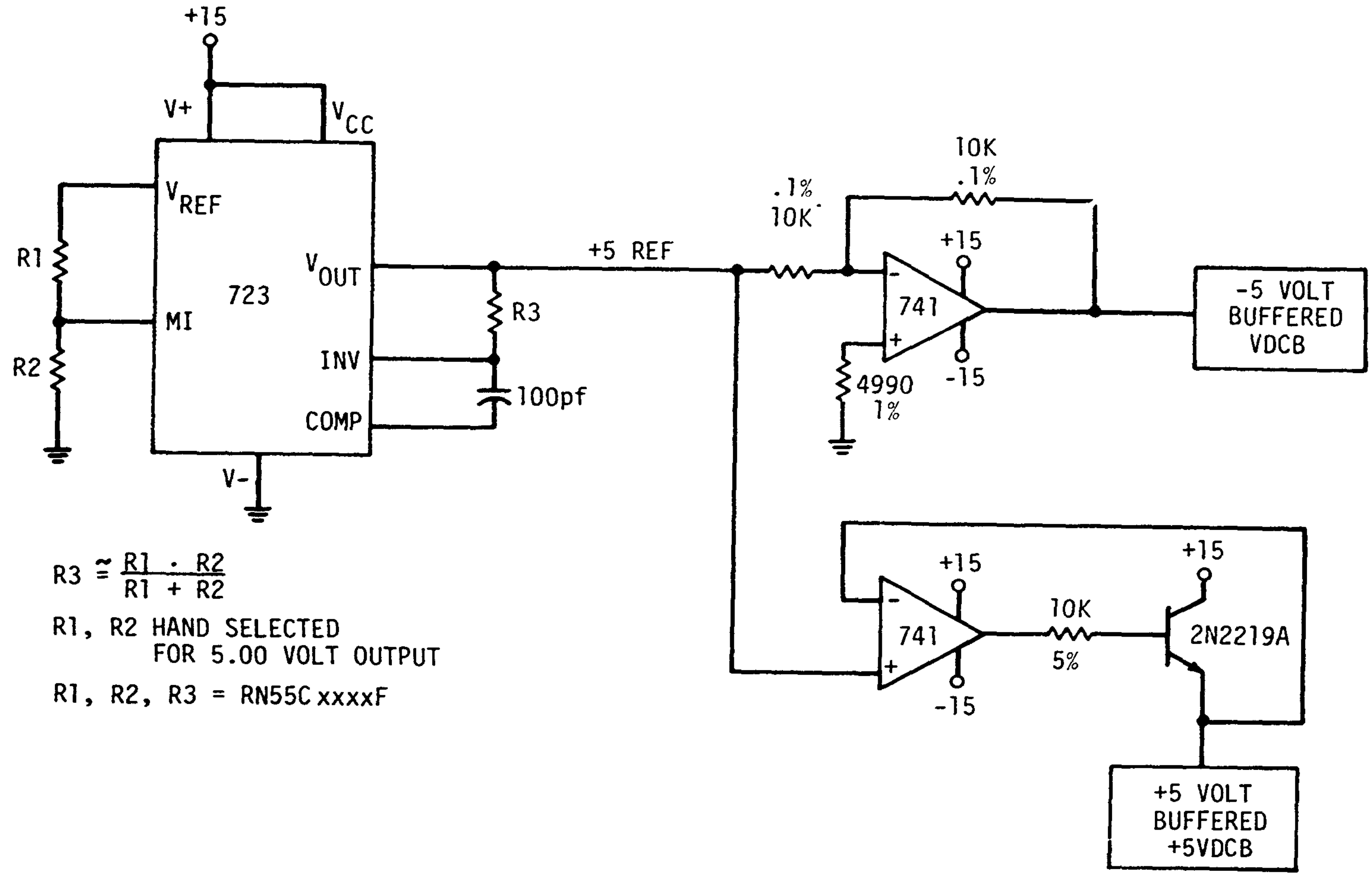
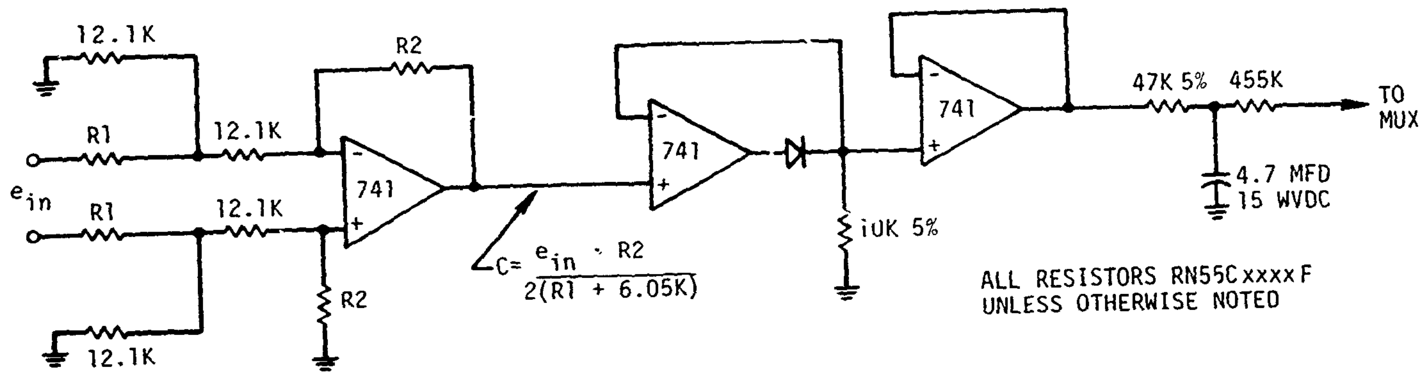


Figure 24. ±5 Volt Buffered Reference Voltages.



$$e_{odc} = \frac{e_{in}\ R2}{2(R1 + 6050)} \cdot \frac{1}{2} \cdot \left(\sqrt{2} \cdot \frac{2}{\pi}\right)$$

$$e_{odc} = \frac{e_{in}\ R2}{\pi\ \sqrt{2}\ (R1 + 6050)} \quad \text{RIPPLE} < 1/256 \text{ F.S.}$$

e_{in} IS RMS MEASUREMENT

Figure 25. Buffered AC-to-DC Circuit for Roll Attitude, Engine Torque, and References.

filter was mounted to a bracket on the bottom of the case.

Two PC boards were used, one for the analog section and one for the digital section of the recorder. The PC boards were mounted to the side cover plates with standoffs positioned to minimize vibrations.

A 3M connector system was used on the PC boards to enhance maintainability. A retention clip was used to lock the plug to the receptacle. A Cannon-type PSE connector on the front panel provided access for the retrieval unit. This connector was normally capped. A Cannon PDP connector mounted on the rear panel of the case provided connection to both the transducers and the input power.

Gaskets on the side covers were a combination of woven Monel for electromagnetic interference (EMI) protection and sponge silicone to provide a moisture/dust seal. The connector gaskets were Monel-impregnated silicone. Metal slugs were provided as part of the cover gaskets to preclude the possibility of overcompensation of the gaskets. All fasteners were specified to MIL-N-25029.

The flight recorder was mounted in a Barry Controls 3/8 ATR tray with helicopter shock mounts.

Data Transfer Unit (DTU). The original design concept required the DTU to serve a dual role - as a retrieval unit in extracting data from the recorder and storing it on cassette tape, and as a test unit to enable an operator to view the extracted data.

As a brassboard retrieval unit, operator inputs would be requested via a six-character alphanumeric display. The operator inputs would be entered through a numeric keyboard. After these operator inputs were accepted, the recorder, on request of the retrieval unit, would send the counter data, all digitized analog channels, and a repeat of the counter data following a test routine. The retrieval unit stored all information and at retrieval conclusion stored it on cassette tape. The alphanumeric display was used to notify the operator of any failures or incorrect inputs. The software flowchart of the communication between recorder and retrieval unit describes the data extraction procedure and is presented in Figure 26.

Following data retrieval, any of the information resident in the retrieval unit was viewed by entering an address via the keyboard.

Data Processing Software. As stated, the data processing software system was to consist of three major elements: the Initial Processing System, the Fatigue Damage Assessment System, and the Component Tracking Management System. Detailed information concerning each of these systems and their operation had been previously planned (Reference 1, p. 76).

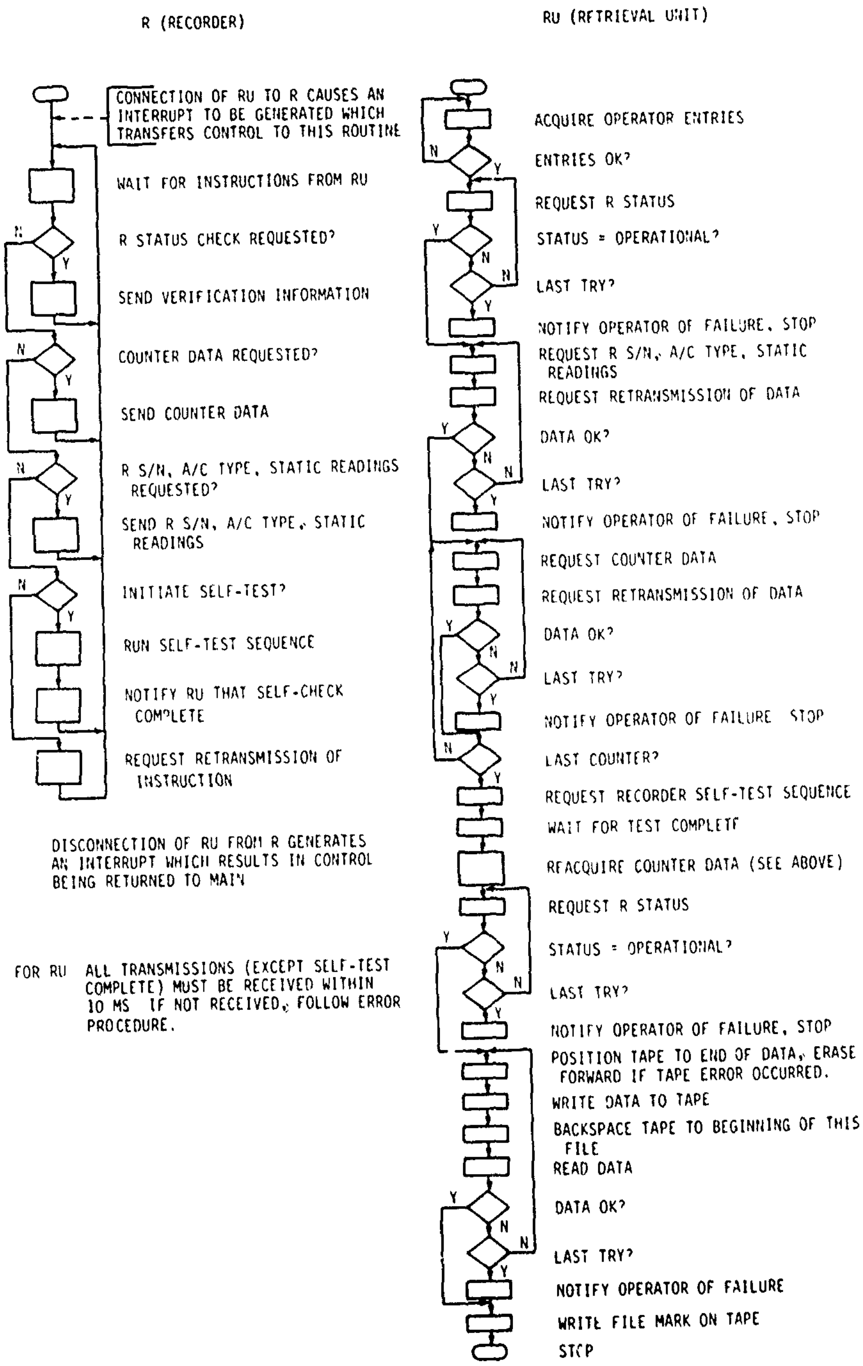


Figure 26. Retrieval Unit Recorder Communications.

The brassboard and supporting software evaluations were essentially complete by the time Critical Design Review was completed. The conceptual approach was found satisfactory and preparation of test articles was begun. It was recognized that reliability was of primary importance to the SIRS equipment. Thus a reliability assessment was provided.

Reliability Analysis

A reliability analysis was performed using MIL-HDBK-217B and the component manufacturers' data to predict the mean-time-between-failure (MTBF) for the SIRS recorder. The results of the analysis are summarized in Table 20. The calculated MTBF of about 7300 hours for the SIRS recorder includes consideration of a helicopter operational environment in a worldwide scenario. As such, the 7300 hours MTBF is considered realistic. The analysis did not include the processor board batteries, which in this application were expected to have a lifetime well in excess of 6 months. Furthermore, although only one such battery is required, a second battery is included in the design as a redundant feature to enhance the operational reliability. The MTBF of the transducers and installation kit is about 1400 hours, resulting in an overall system MTBF of about 1200 hours. However, loss of a transducer input does not result in invalid recorded data. The missing input can be synthesized during data processing. In addition, periodic calibrations and other maintenance actions should identify potential transducer failures before they occur. Operation of four recorders during software development, burn-in prior to qualification test, and qualification and flight tests resulted in an accumulated operating time in excess of 500 hours. Only one failure was recorded. This occurred during the environmental portion of the qualification tests. Upon conclusion of the temperature-humidity-altitude test, the recorder did not operate. The cause was identified as leaking batteries and the resulting contact corrosion.

Laboratory Qualification Testing

The qualification testing was designed to assess the performance of the SIRS recorder in simulated EMI/electromagnetic compatibility and normal airborne environments conforming to MIL-STD-461/462 and MIL-STD-810, respectively. Table 21 summarizes the test conditions for each environment. Figure 27 shows a typical test setup.

Two recorders were subjected to the testing: S/N 005, which was packaged in a steel box, and S/N 1007, which was contained in an aluminum box for potential weight savings if the aluminum base proved adequate during the testing. S/N 005 was used in the normal airborne environment test while S/N 1007 was

TABLE 20. RELIABILITY ANALYSIS SUMMARY

Component	Part No.	Failure Rate(a)	MTBF(hr)
Processor Board	074032D30014	55.9854	17,862
Signal Conditioning Board	074032D30019	50.6592	19,740
Power Supply	C5/T15/165/x	16.6667	60,000
Filter	RF6125	0.0560	17,857,143
Termination Assembly	074032C30011	0.5820	1,718,213
Internal Cables/ Connections	-	11.7040	85,441
Connector	KP5E02A12-10S	1.8630	536,769
SIRS Total		137.5163	7,272
Circuit Breaker	MS22073-3/4	1.9650	508,906
Gross Weight Sensor	DCMC3FF41	254.2370	3,934
OAT Sensor	S6B	97.1930	10,289
Altitude Sensor	1332A3	94.5200	10,580
Airspeed Sensor	1332D1	94.5200	10,580
Accelerometer	SA109-B-1/+3SL	174.1940	5,741
Miscellaneous Connections	-	0.7300	1,369,863
Transducers and Installation Kit Total		717.3590	1,394
System Total (b)		854.8753	1,170

Notes:

(a) Estimated number of failures per million hours.
(b) Excludes aircraft inputs.

TABLE 21. SUMMARY OF QUALIFICATION TESTS

a. MIL-STD-461/462 Tests

Test Method	Description	Remarks
CE01	Conducted Emission, 30 Hz to 20 kHz, Power Leads	Info. Only
CE02	Conducted Emission, 30 Hz to 20 kHz, Control and Signal Leads	Info. Only
CE03	Conducted Emission, 20 kHz to 50 mHz, Power Leads	
CE04	Conducted Emission, 20 kHz to 50 mHz, Control and Signal Leads	Info. Only
CS01	Conducted Susceptibility, 30 Hz to 50 kHz, Power Leads	
CS02	Conducted Susceptibility, 50 kHz to 400 mHz, Power Leads	
CS06	Conducted Susceptibility, Spike, Power Leads	
RE02	Radiated Emission, 0.014 to 10 gHz, Electric Field	
RS02	Radiated Susceptibility, Magnetic Induction Fields	
RS03	Radiated Susceptibility, 14 kHz to 10 gHz, Electric Field	

b. MIL-STD-810 Tests

Test Method	Procedure	Description
504	I	Temperature Altitude: -25°C to 50°C, 0-20,000 ft.
518	I	Temperature, Humidity, Altitude: -40°C to 50°C, 0-95% RH, 0-20,000 ft.
507	I	Humidity: 0-95% RH
513.1	II	Acceleration
511	I	Explosive Atmosphere
510	I	Dust
514.1	I	Vibration (Category C Equipment)

Figure 27. Test Setup for SIRS Recorder Qualification.

used in the EMI/EMC environment test; its test results could be applied to S/N 005 whereas the converse would not be possible.

The tests were successful in that the few operational discrepancies that occurred during the tests could be eliminated by simple corrective actions. The correction actions were such that the high level of confidence in their effectiveness precluded the requirement for retests. Of the five discrepancies observed, four occurred during the EMI tests and three of the four were correctible by proper termination of shields in the signal cable, shorter wire lengths, and improved wire routing. The fourth discrepancy was due to the SIRS recorder logic test program and could not be attributed to the EMI environment. The fifth discrepancy was a leaking battery condition that developed during temperature-humidity-altitude testing. A suitable battery replacement eliminated the problem.

Phase I Prototype Flight Test

The prototype flight test was held and the program was formally introduced to Fort Rucker personnel on 5 November 1976.

Instrumentation System. To obtain the data for the validation of the SIRS recorder, two Century Model 409B oscillograph recorders, each with 14 data channels and capable of recording numerous dynamic parameters on 3-5/8-inch-wide photosensitive paper, were used in this program. One oscillograph was to record FCR (Flight Condition Recognition) data and the other to record SIRS flag data. The FCR oscillograph recorded the dynamic parameters that would permit identifying the various flight conditions encountered during the flight test program. The SIRS flag oscillograph recorded the various SIRS parameter levels that would trigger the logic routine operations and consequently provided the data to verify the functioning of the logic routines.

In general, each oscillograph had 12 channels available for recording the in-flight parameters. Of the remaining two channels, one was used to delineate a time pattern reflecting a 1-minute cycling, and the other was used to trace a static line for measurement reference. Table 22 presents the parameters recorded on each oscillograph. As apparent in this table, several parameters were recorded by both oscillographs so that the two oscillographs could be readily correlated. The FCR oscillograph parameters were recorded as analog values while the flag oscillograph parameters were presented either as analog values for the parameters in common with both oscillographs or as ranged data for the output of the SIRS recorder.

The signal conditioning units used to regulate the voltage signals from the various transducers were the Technology Incorporated Models 074037D30007-1 and -2 for the flag and the FCR oscillographs, respectively.

TABLE 22. RECORDED PARAMETERS

Parameter	FRC Oscillograph	Flag Oscillograph
Airspeed	Analog	Range
Pressure Altitude	Analog	-
Outside Air Temperature	Analog	-
Density Altitude	-	Range
Main Rotor Speed	Analog	Range
Vertical Acceleration	Analog	Analog and Range
Engine Torque	Analog	Analog and Range
Roll Attitude	Analog	Range
Pitch Attitude	Analog	Range
Gross Weight	-	Range
Touchdown	-	Range
Time	Analog	Analog
Reference	Analog	Analog

For a description of the recording system, refer to Chapter 3.

Installation of Recording System. The SIRS recorder was installed in the helicopter's battery compartment on a shelf accessible from the right-hand side of the helicopter. The airspeed and altitude transducers were mounted on the left-hand side of the aircraft in the area adjacent to the pilot's compartment where the aircraft's pitot and static system was accessible. The vertical accelerometer was mounted on a bracket attached to the bulkhead beneath the transmission. The outside air temperature transducer was mounted on the skin of the helicopter on the underside at Station 220. Rotor speed was taken from the helicopter's rotory tach generator. Engine torque was taken from the engine torque transmitter. A circuit breaker was installed in the pilot's right-hand aft circuit breaker panel and was connected to the dc bus to provide 28 Vdc power. Provisions were made to take the roll and pitch attitude signals from the aircraft's roll and pitch gyro located in the same area as the airspeed and altitude transducers. The gross weight sensors were installed at the midpoint of the fore-and-aft skid crosstubes. Cabling between the SIRS recorder and transducers was routed through the compartments along the underside of the helicopter. Figure 28 is an outline drawing of the AH-1G helicopter showing the recorder system component locations.

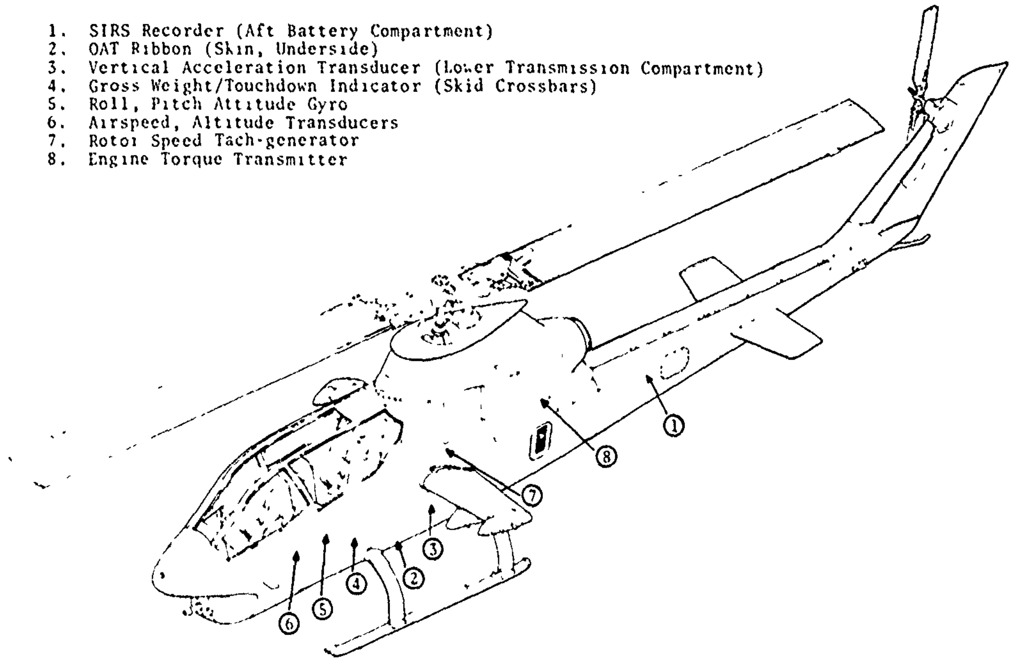


Figure 28. Installation Schematic.

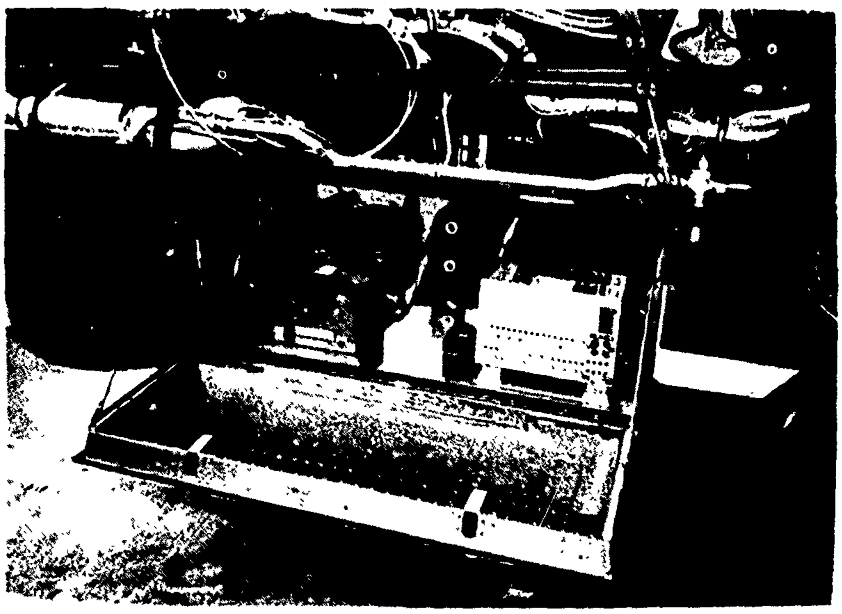


Figure 29. Flight Test Instrumentation System.

The instrumentation system used to evaluate the performance of the SIRS recorder, including the FCR oscillograph, flag oscillograph, signal conditioning system, and digital-to-analog converter, was mounted in the ammunition bay under the pilot and gunner's compartment. In addition, a junction box was installed in the battery compartment to tap into the SIRS recorder's analog and digital flag signals. Figure 29 is a photograph of the flight test instrumentation system.

The SIRS and flight test recording systems were installed and checked between 23 February and 15 March 1977.

Recorder Flight Testing. The flight performance of the SIRS recorder was evaluated by flying various flight conditions and by analyzing the degree to which the SIRS recorder could identify and correctly time the flight conditions. Examples of the flight conditions flown are listed in Table 23. In addition, several nap-of-the-earth flights, both simulated and actual, were performed.

Seven useful data flights, which yielded 7.5 hours of in-flight data, were made during the 4 weeks of the flight test program. An additional 22 flights, yielding 19.9 hours of in-flight data, were made; these flights included instrumentation check flights, nap-of-the-earth training flights flown in conjunction with the test program, and landing check flights. Although limited data from these flights were processed to verify the operation of the SIRS recorder, they were not specifically used to validate the recorder performance. Table 24 summarizes the 29 flights.

During the early portions of the flight test program, each flight generally lasted an hour and most of the flight conditions listed in Table 23 were flown. Beginning on flight 21, the digital-to-analog converter used to establish the signal levels for the flag oscillograph malfunctioned occasionally. The malfunction was a random disruption of all the traces on the flag oscillograph. Consequently, the later flights in the program were generally shorter and designed to investigate fewer flight conditions with only the FCR oscillograph.

Recorder Performance. The following summary of the SIRS recorder performance consists of detailed discussions of how the recorder identified and recorded occurrences of flight conditions, time within certain prescribed flight conditions, and maximum parameter occurrences. Not all of the 22 flight condition categories will be discussed in detail. Rather, examples of each of the three types of data recording techniques, that is, occurrences, times, and maximums, will be presented. In addition, during the test program several of the encountered flight conditions required logic modifications or improvements before they could be identified. These modifications are discussed in general, but an example of a required logic change is illustrated.

TABLE 23. FLIGHT TEST FLIGHT CONDITIONS

Rotor Start/Stop	Dive:
Level Flight	Symmetric
Hover:	To Left
IGE	To Right
OGE	Pullout:
Quick Stop:	Symmetric
IGE	To Left
OGE	To Right
Full Power Climb	Pullup (Cyclic Climb):
Maximum Performance Takeoff	Symmetric
Maximum Rate Acceleration	To Left
Autorotation:	To Right
Power to Autorotation	Turns:
Steady	Normal
Turns	Gunnery
Landings	S-Type
Approach and Landing	

TABLE 24. FLIGHT LOG SUMMARY

Flt. No.	Predominant Maneuvers	Valid Data SIRS	FCR	Flag	Flight Duration(hr)
1	Ground Run		*		-
2	Functional Check		*		0.4
3	Functional Check		*		0.3
4	Pilot Currency		*		1.0
5	Entire Profile	*	*		1.5
6	Level Flight, Turns	*	*		0.5
7	Level Flight, Turns	*	*		0.7
8	Level Flight, Turns		*		0.7
9	Functional Check	*	*		0.3
10	Level Flight, Turns	*	*	*	0.8
11	Entire Profile		*	*	1.4
12	Entire Profile	*	*	*	1.0
13	IP Check, Auto Landings		*	*	1.8
14	Dives, Turns	*	*	*	1.0
15	Nap-of-Earth		*		1.5
16	Nap-of-Earth		*		1.5
17	Nap-of-Earth	*	*	*	1.6
18	Nap-of-Earth	*	*		1.7
19	Nap-of-Earth		*		1.8
20	Functional Check	*	*		0.8
21	Entire Profile	*	*		1.5
22	Level Flight, Takeoffs		*		0.6
23	Check Flight	*	*		0.8
24	Level Flight, Quick Stops	*	*		0.5
25	Landing Check	*	*	*	0.3
26	High Gross Weight/ Landing Check	*	*	*	0.3
27	Low Gross Weight/ Landing Check	*	*	*	0.4
28	Level Flight/ Airspeed Check	*	*	*	1.5
29	Low Gross Weight/ Landing Checks, Quick Stops	*	*	*	1.2

Of the flight conditions that are recorded as occurrences, rotor start/stop and takeoff/landing cycles are the principal ones discussed in this section. The timed flight conditions to be discussed include total flight time, cruise, and various types of turns. Finally, this section discusses the measurement of peak vertical accelerations.

Computed Parameters. The SIRS recorder monitors airspeed, pressure altitude, and outside air temperature. From these parameters, the SIRS recorder computes the density altitude, the maximum level-flight velocity, and the limit velocity for the helicopter. In addition, the SIRS recorder monitors inputs from the gross weight sensors and computes gross weight ranges during a flight.

Maximum airspeed limit V_H, which represents the maximum level flight limit for the aircraft and the limit velocity V_L, which is the maximum airspeed permitted for the AH-1G helicopter are calculated from Equations 6, 7, and 8. The density altitude is computed in Equation 9.

Each of these calculations is continuously performed within the SIRS recorder, and the various identified flight conditions are categorized by the appropriate percentage of either of these limits.

Table 25 summarizes the airspeed limits, V_H and V_L, calculated by the SIRS recorder as represented on the flag oscillogram and those calculated manually from the FCR oscillogram for Flight 28. This flight was flown at two density altitudes and was typical of the calculating performance of the SIRS recorder.

The SIRS recorder monitors the input from the two piezoelectric beam sensors and computes a takeoff gross weight. During each flight, this gross weight is reduced at a fixed rate to account for fuel consumption. Throughout the flight, the various flight conditions are each categorized as being in one of three gross weight ranges: below 7750 pounds, 7750 to 8750 pounds, and above 8750 pounds.

As shown in Table 26, the system did not reliably compute the takeoff gross weight, since it yielded correct values for only five of the twelve flights. However, it generally computed the correct gross weight for the first flight of the day as evidenced in the data for Flights 11, 21, and 23. These correct values were due to the ability of the skid landing gear to assume its natural position when the helicopter was positioned on the flight line each morning. The flight test log does not indicate whether the helicopter was refueled before or after it was moved for Flights 31 and 26. The system did operate correctly after the wing stores were removed prior to Flight 27. Except for Flight 14, the system did not correctly compute the takeoff gross weight when the mission was the second or third flight of the day. When the helicopter was refueled

TABLE 25. COMPARISON OF PERCENT V_H AND V_L CALCULATIONS FOR LEVEL FLIGHT CONDITIONS (FLIGHT 28)

Indicated Airspeed	Density Altitude	%V_H FCR	%V_H Flag	%V_L FCR	%V_L Flag
118	2155	0.84	0.8-0.9	0.66	≤0.7
109	2155	0.78	0.65-0.8	0.60	≤0.7
134	2271	0.96	0.9-0.95	0.74	0.7-0.85
127	2327	0.91	0.8-0.9	0.70	0.7
148	2155	1.06	>0.95	0.82	0.7-0.85
134	2348	0.96	0.9-0.95	0.75	0.7-0.85
140	2325	1.01	>0.95	0.78	0.7-0.85
156	2350	1.12	>0.95	0.86	0.7-0.85
166	2300	1.19	>0.95	0.92	0.85-0.95
153	2275	1.10	>0.95	0.85	0.7-0.85
109	6675	0.84	0.8-0.9	0.73	0.7-0.85
103	6648	0.79	0.65-0.8	0.68	≤0.7
120	6600	0.92	0.9-0.95	0.79	0.7-0.85
114	6664	0.87	0.8-0.9	0.76	0.7-0.85
128	6719	0.98	>0.95	0.85	0.85-0.95
124	6694	0.95	0.9-0.95	0.82	0.7-0.85

TABLE 26. TAKEOFF GROSS WEIGHT COMPARISON

Flight No.	Date	Log	Flag	SIPS
11	31 Mar 77	8317	7750-8750	-
12	"	8317	<7750	<7750
13	5 Apr 77	8317	≥8750	-
14	"	8317	7750-8750	7750-8750
21	12 Apr 77	9500	≥8750	≥8750
22	"	9500	<7750	-
23	13 Apr 77	9500	-	≥8750
24	"	9500	-	7750-8750
26	14 Apr 77	9500	-	7750-8750
27	"	8317	-	7750-8750
28	"	8317	<7750	<7750
29	"	8317	<7750	<7750

between flights, the static friction between the skid landing gear and ground prevented the skid gear from readjusting for the increased weight of the fuel.

The algorithm used to decrease gross weight due to fuel consumption worked correctly. In addition, during one flight after a landing, the rotor speed decreased below 250 rpm, and the gross weight system updated itself correctly.

Occurrences. The SIRS recorder is designed to monitor the various input parameters and, through the microprocessor logic, to identify occurrences of flight conditions. Such typical flight conditions include rotor start/stop cycles, power-on landings, autorotative landings, high n_z maneuvers, and autorotation-to-power transitions. In this section, the first three occurrences will be discussed.

The SIRS recorder identified the eight rotor starts that occurred during the seven data flights shown in Table 27 and one extra cycle on Flight 12. The extra start was counted because of an accidental pulling of the circuit breaker of the instrumentation system, which caused the signal to behave as though a shutdown was occurring.

In general, the SIRS recorder correctly identified the normal landings performed during the flight test program. Table 28 summarizes the normal and autorotative landings detected by the SIRS recorder and identified on the FCR oscillogram. An example of a typical landing is shown in Figure 30, which includes the FCR and flag oscillograms. Table 28 shows differences between the FCR and SIRS data due to two types of problems, one in Flights 12, 28, and 29, and the second in Flights 23, 24, 28, and 29.

The normal landings of Flights 12, 28, and 29 not recorded by the SIRS recorder were missed because the recorder's logic requires 10 seconds of flight before subsequent landing can be considered valid, and 5 seconds on the ground before the landing is considered valid. During Flights 12, 28, and 29, multiple landings were made as part of the investigation of the performance of the gross weight sensing system; not all of these takeoffs and landings satisfied the logic of the recorder. No changes to the recorder logic are planned since this problem is not considered one that will exist in the operational environment.

For the identified autorotative landings of Flights 23, 24, 28, and 29, the logic had to be modified because the SIRS recorder was identifying normal power-on landings performed at high gross weights as autorotative landings. This occurred because the engine torque dropped below 5 psi sometime during the 10 seconds prior to touchdown. The subsequent logic changes will preclude the misidentification of normal landings.

Only three full autorotative landings were performed during the flight test program because of pilot restrictions and availability. All of these landings occurred during

TABLE 27. COMPARISON OF FLIGHT LENGTH AND ROTOR STARTS

Flt.No.	Flt. Time (min) FCR	Flt. Time (min) SIRS	Rotor Starts FCR	Rotor Starts SIRS
12	55.60	56.32	1	2 (a)
14	52.57	52.72	1	1
21	73.86	74.69	1	1
23	37.77	38.03	1	1
24	25.29	25.39	1	1
28	85.81	85.69	1	1
29	60.97	61.89	2	2

Note:

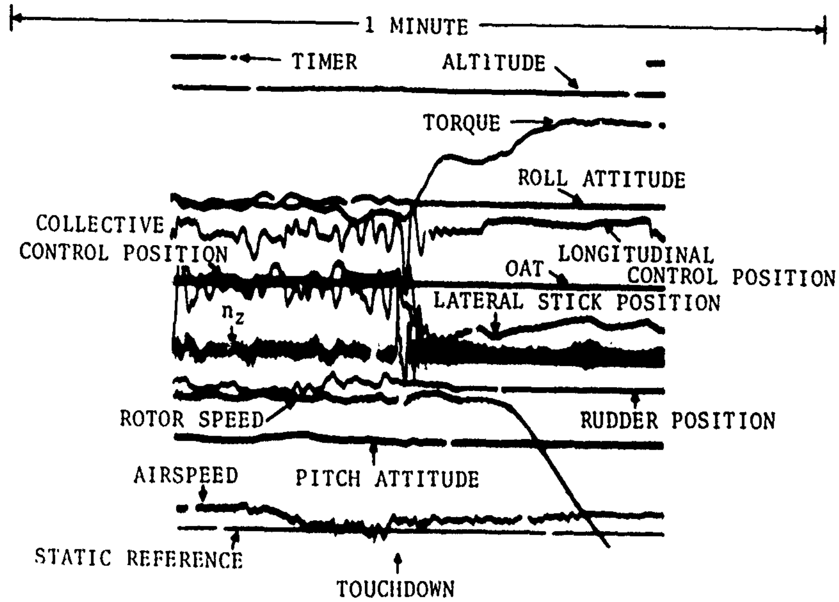
(a) Caused by accidently pulling circuit breaker for the instrumentation's electrical system.

TABLE 28. COMPARISON OF LANDINGS

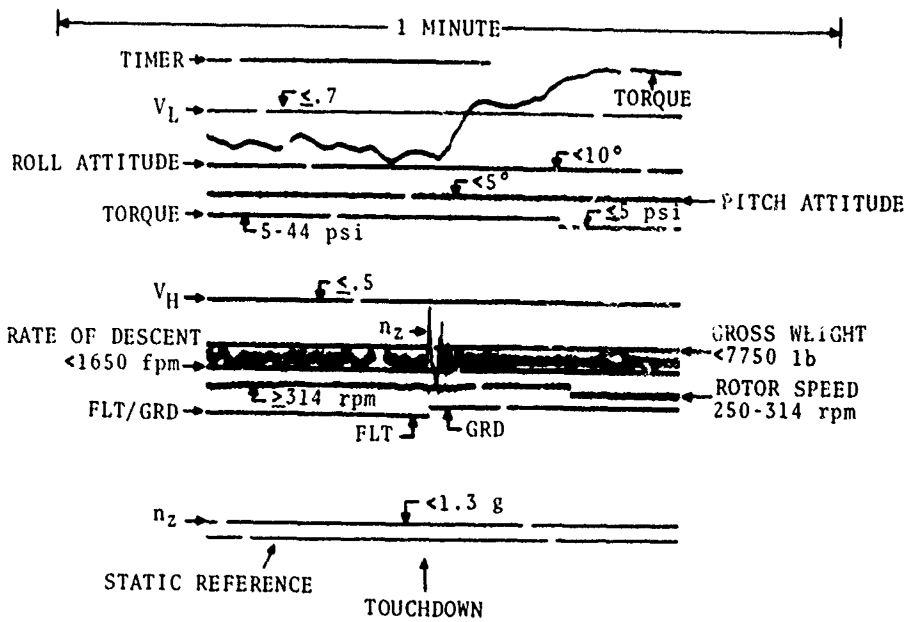
Flt.No.	Normal Landing FCR	Normal Landing SIRS(a)	Autorotative Landing FCR	Autorotative Landing SIRS(a)
12	4	2	0	0
14	1	1	0	0
21	9	9	0	0
23	5	4	0	1
24	4	3	0	1
28	3	1	0	1
29	13	7	0	2

Note:

(a) Discrepancies in the data are discussed in the text.



(a) FCR Oscillograph



(b) Flag Oscillograph

Figure 30. Normal Landing.

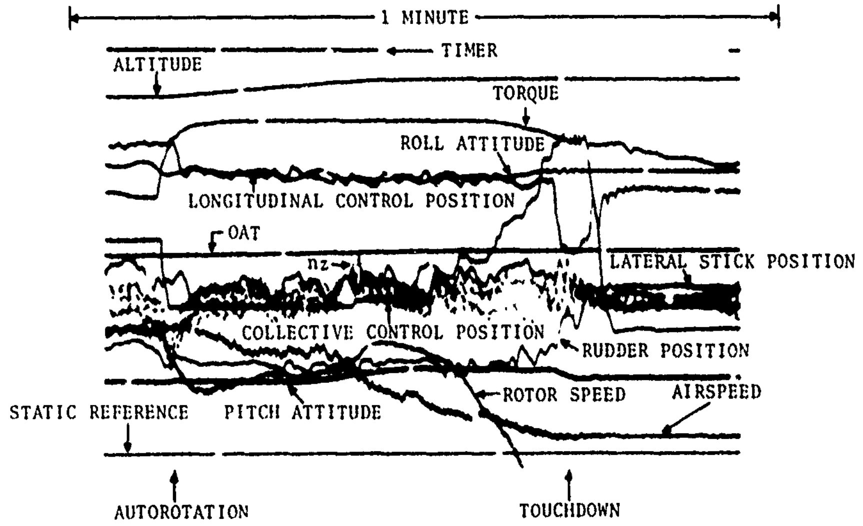
Flight 13. Unfortunately, the temporary mercury batteries, installed after the failure of the lithium batteries in the qualification testing, lost contact in flight and the recorder memory was lost; these slightly undersized batteries were subsequently soldered in place. However, the FCR and flag oscillograms in Figure 31 show that the SIRS recorder would have identified the landing as an autorotative landing since the engine torque was below 5 psi for the entire 10 seconds prior to the landing as required by the SIRS recorder logic.

Timed Flight Conditions. The SIRS recorder can record the duration of flight conditions in a manner similar to the recognition of occurrences procedure. The microprocessor logic identifies the flight conditions according to the individual or collective flight parameter changes, each within a preset range. For example, the duration of flight time is determined by the length of time that the touchdown indicator indicates an airborne condition. Likewise, a turn is identified as the duration of time that roll attitude is beyond the threshold if a vertical acceleration peak in excess of 1.3g occurs sometime during the period; the turn is then characterized by the airspeed and gross weight at which it was performed.

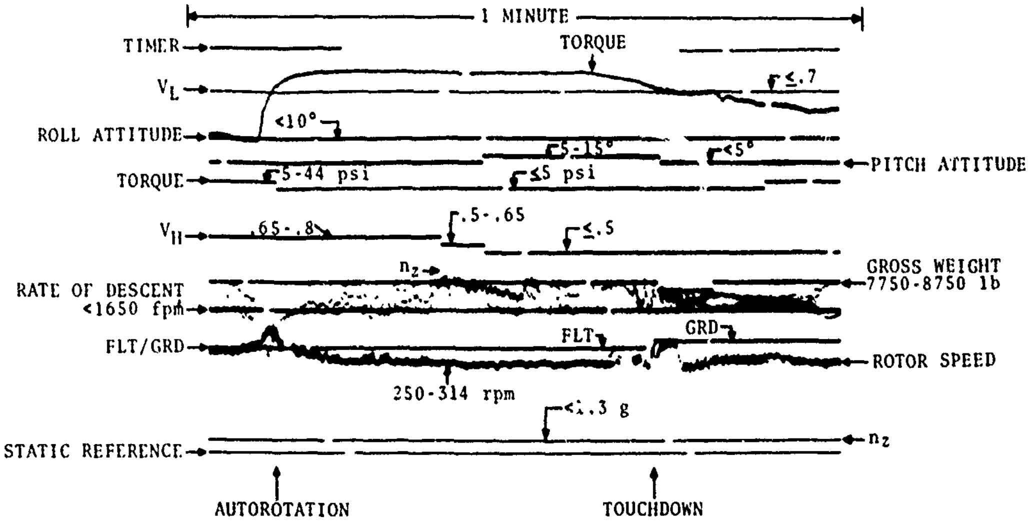
The durations of the seven data flights as measured by the FCR oscillograph and the SIRS recorder are listed in Table 27. The maximum variation in the two measurements is 1.5 percent; it should be noted that the potential for error in measurement is greater with the oscillograph than with the SIRS recorder because of the mechanical aspects of the oscillograph.

In addition to the total flight time, the SIRS recorder also measured the time spent in cruise at various airspeed levels. Low-speed flight is defined by speeds of 50 to 65 percent V_H; high-speed flight is defined by speeds of 65 to 95 percent V_H; and maximum-speed flight is defined by speeds in excess of 95 percent V_H. For all level flight conditions, the airspeed is converted to the equivalent percent V_H for that gross weight and density altitude condition. As presented in Table 29, the SIRS recorder accurately measured the time in various cruise conditions. For the same flight, a comparison of measured and recorded values for V_H throughout the cruise conditions are presented in Table 30.

As discussed earlier, the SIRS recorder includes logic to identify various types of turns, including normal, gunnery, and gunnery S-turns. The turns are categorized by airspeed and vertical acceleration for a given gross weight condition. For Flight 14, normal, gunnery, and S-turns were analyzed by processing data from the FCR and flag oscillographs and comparing these data with the output of the SIRS recorder. As shown in Table 31, the agreement is very good between the flag and SIRS data.



(a) FCR Oscillograph



(b) Flag Oscillograph

Figure 31. Autorotative Landing.

TABLE 29. COMPARISON OF CRUISE TIMES FOR FLIGHT 14

	Flag Oscillograph	SIRS
Low-Speed Flight	11 sec	12 sec
High-Speed Flight	934 sec	934 sec
Max. Speed Flight	53 sec	54 sec

TABLE 30. COMPARISON OF PERCENT V_H CALCULATIONS DURING CRUISE FOR FLIGHT 14

Flight Condition	Indicated Airspeed	Density Altitude	$\%V_H$ FCR	$\%V_H$ Flag
Low-Speed Flight	91	2410	0.65	0.5-0.65
"	84	1048	0.59	0.5-0.65
High-Speed Flight	100	2492	0.72	0.65-0.8
"	133	2724	0.96	0.9-0.95
"	125	2807	0.91	0.8-0.9
"	100	2409	0.72	0.65-0.8
"	124	2291	0.89	0.8-0.9
"	131	2256	0.94	0.9-0.95
"	110	2208	0.79	0.65-0.8
"	124	2291	0.89	0.8-0.9
"	127	2005	0.91	0.8-0.9
"	113	2009	0.81	0.65-0.8
"	132	1969	0.94	0.9-0.95
"	115	2005	0.82	0.65-0.8
"	120	2005	0.86	0.8-0.9
"	131	1995	0.94	0.9-0.95
"	126	1969	0.90	0.8-0.9
"	124	1900	0.89	0.8-0.9
"	134	1827	0.96	0.9-0.95
"	135	1298	0.95	0.9-0.95
"	124	1252	0.88	0.8-0.9
"	106	1174	0.75	0.65-0.8
Max. Speed Flight	140	2800	1.01	>0.95
"	140	2020	1.00	>0.95
"	142	2030	1.01	>0.95
"	143	1703	1.02	>0.95

TABLE 31. COMPARISON OF VARIOUS TURNS FOR FLIGHT 14

Type	Gross Weight	Duration (sec)		
		FCR	Flag	SIRS
Normal Turn	<7750	234	222	222
"	7750-8750	40	39	39
Gunnery Turn	<7750	28	27	27
"	7750-8750	167	158	161
Gunnery S-Turn	7750-8750	140	139	138

The measurement accuracy of the FCR and flag oscillographs is less than that of the SIRS recorder because the crystal clock in the recorder functions more precisely than the mechanical drives in the oscillographs. Minor variations in the drive speed of the oscillographs cause corresponding variations in the timed events. For illustrative purposes, Figure 32 presents the FCR and flag oscillograms for a typical turn. This turn, as recorded by the SIRS recorder lasted 39.2 seconds. In comparison, by analyzing when the roll flag changed from within threshold to outside threshold and then back again, the turn duration would be 39 seconds. Note that near the end of the turn, the n_z flag changed from threshold to the range of 1.3 to 1.5g. In the FCR chart, the turn duration is slightly longer, 40 seconds, since the turn was identified at the instant of roll attitude change rather than when it passes through 10°.

Maximum Parameter Value. The SIRS recorder can identify the maximum value of a parameter during the interval between data retrievals. During the flight test program, the maximum values of vertical acceleration and V_L (limit velocity) were recorded.

Table 32 compares the maximum n_z peaks identified by the SIRS recorder during each flight with the corresponding values read from the FCR oscillograph. The largest positive peak recorded during the program was 2.73g, which occurred during a turn at an airspeed of 97 percent V_H and with a roll angle greater than 50°, as shown in Figure 33. The lowest positive peak recorded during the program was 1.08g, which occurred in a hover during Flight 25.

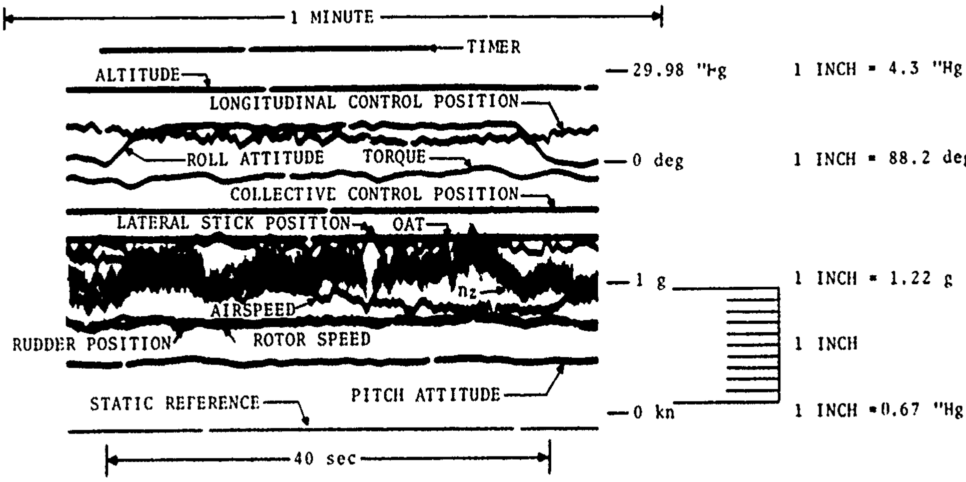
TABLE 32. COMPARISON OF MAXIMUM n_z VALUES

Flight No.	Flight Condition	Maximum n_z (g) FCR	Maximum n_z (g) SIRS
10	Turn	1.4	1.4
12	Dive	2.2	2.3
14	"	2.3	2.3
21	Turn	2.7	2.7
23	Dive	2.5	2.5
24	Quick Stop	1.6	1.6
25	Hover	1.1	1.1
26	"	1.1	1.1
27	Turn	1.7	1.7
28	Cyclic Pullup	1.6	1.6
29	Autorotation to Power	1.5	1.4

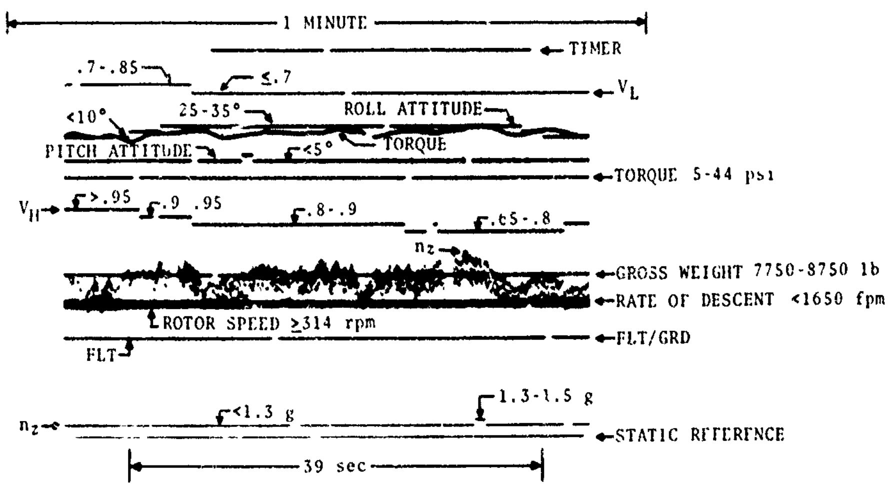
Although the SIRS recorder was programmed to also identify the maximum V_L condition, the lack of a time delay in the recorder caused false V_L values as the recorder and transducers were powered up. Since the altitude transducer has an equivalent altitude of 21,200 feet at zero volts, during the power-up cycle the recorder incorrectly calculated the V_L value. The software logic has since been changed to include a time delay that will prevent erroneous calculations. The recorder capability of measuring maximum V_L peaks has since been demonstrated in the laboratory. In addition, follow-on IOT&E flight tests with the AH-1S have confirmed the laboratory findings.

Summary and Conclusions. The purpose of the Phase I testing was to verify that the SIRS recorder would operate reliably in an operational helicopter environment and yield flight data. The SIRS recorder successfully demonstrated that it can perform its intended function.

Minor improvements recommended for the SIRS recorder hardware and software were incorporated in the SIRS recorders assigned to the Phase II Operational Evaluation. No major changes in the recorder design were required.



(a) FCR Oscillograph



(b) Flag Oscillograph

Normal Turn Time	
SIRS	39 sec
Flag Oscillograph	39 sec
FCR Oscillograph	40 sec

Figure 32. Normal Turn.

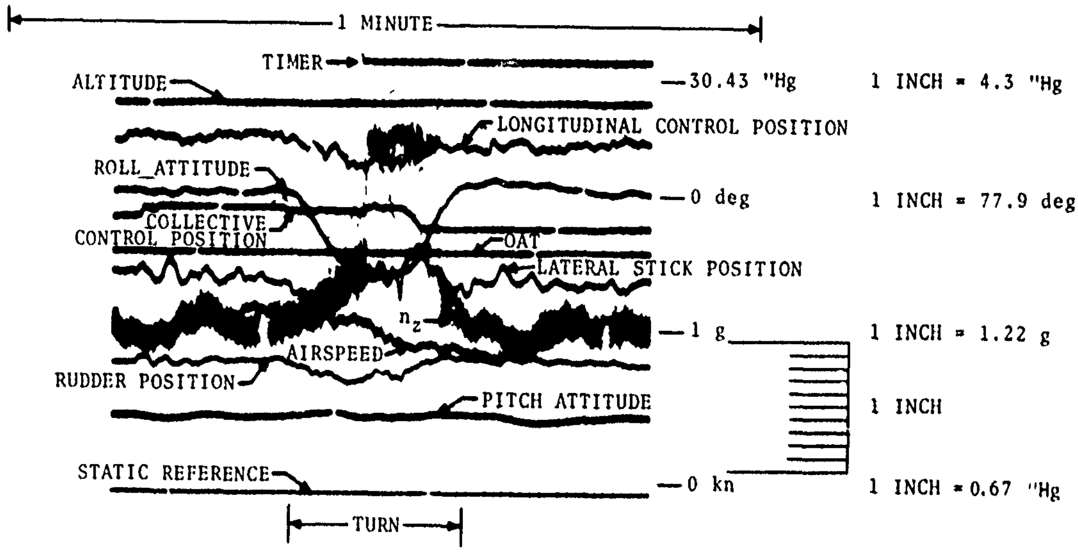


Figure 33. FCR Oscillograph Showing the Largest Positive n_z Peak Recorded During the Program.

The application of the lift link system to the AH-1G was to be researched further; if acceptable results were obtained, it would be incorporated into the SIRS recorder system. In addition, the measurement of pitch in conjunction with the lift link should be considered as a method for decreasing the sensitivity of the lift link system to center-of-gravity changes.

With the incorporation of the recommended hardware and software improvements, the SIRS recorder was declared acceptable for the Phase II Operational Evaluation.

IOT&E

The IOT&E was entitled "Phase II Operational Flight Test for the SIRS AH-1G Program." It was concerned with determining if there were any deficiencies that would inhibit or limit the operational employment of the system. In addition, this was the opportunity to show the user the design that his original concepts produced, what he could expect to accomplish with the system, and, more importantly, what it would cost the user in terms of resources and manpower to accomplish his operational task.

The major objectives of the IOT&E were to:

- Estimate the operational effectiveness and suitability of the system as well as other operational aspects of its military utility.
- Identify any operational deficiencies.
- Recommend and evaluate desirable changes and trade-offs in production configuration.
- Obtain operational information for:
  - Refinement of official program operating and support cost estimates.
  - Identify system characteristics or deficiencies that significantly impact O&S costs.

IOT&E Test Support

During October 1977 the test article installation was essentially completed. At the time of departure of the installation team from Fort Rucker, four of five SIRS recorders were installed and operational. The fifth recorder was not installed because of a malfunctioned vertical accelerometer

that was being repaired. The helicopters in which the recorders were installed are listed below:

Aircraft	Recorder Serial Number
66-15254	1008
66-15252	1009
66-15286	1010
66-15473	1011
66-15356	Installation of 1012 completed December 1977

A data collection trip was made on 15-17 November 1977 to Fort Rucker to retrieve data from the four SIRS recorders and to perform any required maintenance. The status of each recorder was summarized by aircraft tail number. The report at that time was as follows:

> "66-15254 - System Functioning properly."
>
> "66-15252 - Aircraft is in maintenance hangar for replacement of rotor mast. System was inoperative due to large unbalance in the strain gauge bridge. We were unable to compensate for the unbalance and traced the problem to a faulty strain gauge. It will require the installation of a new instrumented lift link."
>
> "66-15286 - Attempted to retrieve data prior to the morning mission and found the system inoperative. Investigation showed that the strain gauge bridge had been destroyed during aircraft maintenance. The strain gauge bridge appeared to have been hit with a wrench. It will require the installation of a new instrumented lift link."
>
> "66-15473 - System functioning properly."
>
> "66-15356 - System inoperative due to faulty n_z transducer. (Sent to factory for repair.)"

A data collection trip was made on 27-29 December 1977 to Fort Rucker to retrieve data and to perform any required maintenance. The status of each recorder was summarized by aircraft tail number. The report of findings at that time was as follows:

"66-15254 - Retrieved data on 28 December 1977. Upon checking the static gross weight parameter, a zero condition was found. Further investigation found a negative 0.3-volt signal from the gross weight in-line amplifier. Rebalancing of the strain gauge bridge produced a 70-count static indication on the Retrieval Unit. While closing up the aircraft, the Retrieval Unit was left on (approximately 3 minutes) and the 70-count reading drifted down to 46 counts. The 46-count reading did not drift over the next 1-minute interval. The Retrieval Unit was turned off for approximately 2 minutes and back on to monitor gross weight. A 54-count reading was observed this second time and a slow drift downward to 50 counts took an estimated 52 seconds. It appears that the strain gauge bridge is drifting."

"66-15252 - Aircraft is still in maintenance hangar awaiting rotor mast change. The strain gauge bridge is still unbalanced due to a faulty bridge. The system is still inoperative and will need a new instrumented lift link."

"66-15286 - System inoperative due to a completely destroyed strain gauge on the lift link. This system will need a new instrumented lift link."

"66-15273 - Data retrieved and static condition checkout show this system functioning properly."

The IOT&E flight test continued into the February 1978 time frame. By that time the AH-1G program had been phased down and replaced by the follow-on IOT&E with the AH-1S used as the test vehicle.

Evaluation of an AH-1G Fleet Operating Parameter That Impacts O&S Costs

It was noted that conventional calculated component damage was arrived at by using official logbook hours reported on each airframe. Further, it was observed that calculated SIRS spectrum damage and component damage arrived at by using recorder clock time would both lead to extended service lives of the

10 high-value, fatigue-sensitive components under study in this program. This is attributed to the fact that the recorder electronics is made to function only at the onset of events leading to component damage. This typically begins at rotor start. Component damage is not accumulated during engine run-up although the aircrew would be expected to include all operating times in logbook hours independent of whether they contribute to component damage. An example of the results for aircraft 66-15473 is reproduced in Table 33. A statistical treatment of the calculated component damage throughout this limited flight test program may be seen in Table 34.

The planned DT&E and IOT&E programs for the SIRS concept were completed in December 1977. The follow-on IOT&E was phased in at that time with the AH-1S as the test vehicle. While the AH-1G DT&E and IOT&E programs were quite compressed, a number of significant findings were derived from the effort.

TABLE 33. CALCULATED COMPONENT DAMAGE

Component	SIRS Spectrum	Predicted Spectrum	
		Recorder Hours	Logbook Hours
Main Rotor Blade	0.00706	0.05477	0.08227
Main Rotor Yoke Extension	0.0	0.01826	0.02742
Main Rotor Grip	0.0	0.00602	0.00905
Main Rotor Pitch Horn	0.00002	0.00913	0.01371
Retention Strap Ftg/Nut	0.02563	0.02738	0.04114
Swashplate Drive Link	0.00001	0.00548	0.00823
Swashplate Outer Ring	0.00025	0.01826	0.02742
Swashplate Inner Ring	0.00007	0.01826	0.02742
Hydraulic Boost Cylinder	0.00080	0.01826	0.02742
Tail Rotor Blade	0.00130	0.05477	0.08227

TABLE 34. STATISTICAL EVALUATION OF CALCULATED COMPONENT DAMAGE (ALL FLIGHTS)

	SIRS Damage Spectrum	S_x	Flight Hour Damage			
			Recorder Spectrum	S_x	Logbook Spectrum	S_x
Main Rotor Blade	0.01041	0.01139	0.04386	0.02679	0.08491	0.01206
Main Rotor Yoke Extension	0.000594	0.01314	0.01462	0.00893	0.02833	0.00400
Main Rotor Grip	0.01106	0.02957	0.00514	0.00317	0.00910	0.00177
Main Rotor Pitch Horn	0.00023	0.00091	0.00779	0.00480	0.01379	0.00269
Retention Strap Ftg/Nut	0.03272	0.01732	0.02338	0.01439	0.04137	0.00807
Swashplate Drive Link	0.00020	0.00081	0.00468	0.00288	0.00828	0.00161
Swashplate Outer Ring	0.01870	0.06998	0.01559	0.00960	0.02758	0.00538
Swashplate Inner Ring	0.00320	0.00709	0.01694	0.00992	0.02923	0.00432
Hydraulic Boost Cylinder	0.00037	0.00035	0.01462	0.00893	0.02830	0.00402
Tail Rotor Blade	0.02723	0.04352	0.05080	0.02976	0.08771	0.01296

CHAPTER 5.

FINDINGS

DT&E FLIGHT TEST (PHASE I PROTOTYPE FLIGHT TEST)

Software Modifications

During the flight test program, several flight conditions were identified that required computer logic modification to properly identify or time them. These flight conditions are identified in Table 35.

Hardware Modifications

Several findings resulted from the qualification program. Assorted internal wire routing and terminations were shown to need improvement. The lithium battery failed during the temperature-altitude-humidity test. The gross weight system operated correctly during the flight test program in all modes except one. When the helicopter landed at a low gross weight and then refueled, an error was introduced because the skid landing gear could not assume a new position due to the static friction between the skid gear and the ground. This problem could be solved by requiring a brief lift-off and touchdown before flight takeoff so that the skid gear could assume its normal positon for the existing gross weight. This solution, however, is not considered practical in the operational environment.

IOT&E (PHASE II OPERATIONAL EVALUATION)

Following satisfactory completion of the prototype flight testing, it was determined that the follow-on operational test program would be pursued. Five AH-1G aircraft were selected to participate in this program. The aircraft identified for participation in the program were: 66-15254, 66-15252, 66-15286, 66-15473, and 66-15356.

Before the flight test was initiated, a number of modifications to the SIRS equipment were implemented to improve its performance. After transmission lift links were strain gauged and calibrated, and software modifications were made to the EPROM resident software, the mission equipment was installed on the five test aircraft. On aircraft 66-15356, the n_z transducer was inoperative for the first three months of operation. This negated effective data gathering on this airframe for the entire operational test program. During the data retrieval of 15-17 November, the strain gauge deficiencies were noted on the lift links of two aircraft. Aircraft 66-15286 had a defective strain gauge that appeared to have been damaged during a routine

TABLE 35. FLIGHT CONDITION LOGIC MODIFICATIONS

Flight Condition	Modification
Normal/Autorotation Landing	Minor changes to lengthen period required for low torque and average torque values
Gunnery Run Dive	Major logic change (see Chapter 4)
Pullup - Symmetrical and Asymmetrical	Major logic change to be compatible with Dive Logic (see Chapter 4)
Autorotation Time	Minor change to correct software coding error
Full Power Climb	Minor change to provide category for low-speed, high-power climb
Maximum V_L	Minor change to require time delay prior to start of recorder operation
Quick Stops	Minor change to require decrease in airspeed during maneuver

, 9 1

maintenance operation. Aircraft 66-15252 was found to have a defective strain gauge bridge. Thus, three aircraft were essentially unable to provide useful data during the operation test program.

Aircraft 66-15473, and 66-15254 systems were operational for the entire test period from 1 October to 28 December 1977. During that 90-day period, 132.3 hours of data were captured on aircraft 66-15254. A total of 128.7 hours were retrieved from aircraft 66-15473.

Explicit Determination of Gross Weight (GW)

As noted previously, the attempt to determine AH-1G gross weight by strain gauging the landing gear was unsuccessful. During the IOT&E flight test program (Phase II Operational Flight Test), an alternate approach was to strain gauge the lift links to explicitly measure gross weight. The gross weight parameter is important to calculation of fatigue lives of the 10 parts under consideration.

From the R&D standpoint, it was found to be possible to determine GW by instrumenting the lift links. However, the concept produced consistently erratic data, required close technical attention, and was failure prone. The concept involved bonding strain gauges to the lift link. This was generally found unsatisfactory due to lack of good mechanical bond to the shot-peened surfaces. When operative, this was found to be marginally unsatisfactory due to the high vibration environment. Thus from an R&D standpoint, the lift link concept of instrumentation appeared feasible but from an operational viewpoint (IOT&E) the scheme was judged a failure. This short IOT&E suggests that the technique is too exotic for successful fleet-wide, operational deployment.

Tracking of High-Value, Fatigue Sensitive Parts

During the IOT&E flight test program the practical matter of keeping track of the 10 selected parts became difficult. Nevertheless, as parts are installed or removed for whatever reason, SIRS logistical integrity requires close attention to service lives of all parts on all aircraft that are involved. This IOT&E flight test program, while short, was adequate to sharply focus on the need for a simple, effective parts tracking procedure.

DTU Packaging

DTU operators were required to travel from contractor facilities to the responsible test organization at Fort Rucker throughout this limited IOT&E program. The mode of transportation selected, normally commercial air, resulted in considerable experience with operator transportation of the DTU. Early in

the program, operator observations began to accumulate as to the unwieldy nature of the packaging concept selected for this ground support equipment. Flight test time was inadequate for thorough evaluation of this equipment. Thus it was not determined whether an alternative packaging concept would be a nice-to-have operational attribute or a mission-essential factor.

DTU Tape Drive

During the course of this limited IOT&E program, the use of a one-way controller on the DTU tape drive was found to be a defective design concept. During DTU operations requiring tape search, the design concept that uses rewind times to find a specific record consistently resulted in selection of the incorrect record. This was due to system hysteresis from wear and varying ambient temperature, which caused inconsistent operation of the mechanical elements of the winding and rewinding mechanisms.

Use of DTU During Battery Charging Operation

The design concept was found to preclude DTU operations for other tasks during battery recharging operations. This was of no particular import in the R&D environment during DT&I. However, the operational import became clear during the IOT&E phase of this testing. Corrective action is indicated as this attribute of the design reduces maintenance productivity.

Logistics of Data Reduction

The IOT&E portion of the AH-1G flight test program was an opportunity to proof-test the original data reduction concept. In that capacity the contractor emulated the postulated Data Processing Center. The concept is summarized as follows:

> At the Data Processing Center, the recorded data would be converted into assessment of fatigue damage. The effort would be divided into three tasks: initial processing (IPS), fatigue damage assessment (FDAS), and component tracking management (CTMS). Each task, as described in Chapter 3, was developed as a separate system, with appropriate interfaces, to form the data processing system.

During this IOT&E both the IPS and FDAS were satisfactorily demonstrated. No attempt was made to test or evaluate the CTMS.

Statistical Evaluation of Calculated Component Damage

From the test data reported in Chapter 4, it seems apparent that the damage values for the 10 components under consideration differ according to the technique used to calculate the cumulative damage. Here we will statistically test that observation. Three null hypotheses will be tested:

$H_0(1)$: Component damage recorder-derived = Component damage logbook-derived

$H_0(2)$: Component damage SIRS-derived = Component damage logbook-derived

$H_0(3)$: Component damage recorder-derived = Component damage SIRS-derived

The approach used is to take the smallest difference between the respective values for the test of these hypotheses. From Table 34 the smallest delta was found. Table 36 summarizes the deltas and associated calculations. $H_0(1)$ is tested via Main Rotor Grip data. $H_0(2)$ will be tested with Swashplate Drive Link data, and $H_0(3)$ will be tested with Swashplate Outer Ring data. All null hypotheses were rejected at the 5-percent significance level. Sample Calculation 1 using small sampling theory is shown.

Sample Calculation 1

Test Null Hypothesis $H_0(1)$: 0.00514 = 0.00910 (from Reference 8, p. 261) to a 5-percent level of significance:

$N_1 = 16$ $\qquad$ $N_2 = 16$

$\bar{x}1 = 0.00514$ $\qquad$ $\bar{x}2 = 0.00910$

$S_{\bar{x}_1} = 0.00317$ (Std. Error) $\qquad$ $S_{\bar{x}_2} = 0.001777$ (Std. Error)

$V_1 = 0.0000100489$ $\qquad$ $V_2 = 0.0000031577$

8. Tintner, G., MATHEMATICS AND STATISTICS FOR ECONOMISTS, New York: Holt, Rinehart, and Winston, 1965.

$$S^2_{\overline{x}_1-\overline{x}_2} = \frac{[N_1-1)V_1 + (N_2-1)V_2](N_1+N_2)}{N_1\ N_2(N_1+N_2-2)}$$

$$= \frac{[(16-1)0.0000100489 + (16-1)(0.0000031577)](16+16)}{16(16)(16+16-2)}$$

$$= \frac{[15(0.0000100489) + 15(0.0000031577)](32)}{16(16)(30)}$$

$$= \frac{(0.0001507335 + 0.0000473655)(32)}{7680}$$

$$= \frac{(0.000198099)32}{7680} = \underline{\underline{0.0000008254}}$$

$$t(\text{empirical}) = \frac{(0.00514-0.00910)}{8.254 \times 10^{-7}} = 4797.60$$

n (degree of freedom) = $N_1 + N_2 - 2 = 16 + 16 - 2 = 30$

t (at 5-percent significance) = 2.042

Since t(empirical) >> t(required at 5-percent significance), null hypothesis is rejected.

Of final concern is whether the standard deviations observed during the IOT&E flight test are statistically substantiative. Therefore three additional hypotheses will be tested:

$$H_0(4):\quad \sigma\begin{pmatrix}\text{Component damage}\\ \text{recorder-derived}\end{pmatrix} = \sigma\begin{pmatrix}\text{Component damage}\\ \text{logbook-derived}\end{pmatrix}$$

$$H_0(5):\quad \sigma\begin{pmatrix}\text{Component damage}\\ \text{SIRS-derived}\end{pmatrix} = \sigma\begin{pmatrix}\text{Component damage}\\ \text{logbook-derived}\end{pmatrix}$$

$$H_0(6):\quad \sigma\begin{pmatrix}\text{Component damage}\\ \text{recorder-derived}\end{pmatrix} = \sigma\begin{pmatrix}\text{Component damage}\\ \text{SIRS-derived}\end{pmatrix}$$

The same methodology previously used is repeated here. $H_0(4)$ will be tested via swashplate drive link data. $H_0(5)$ will be tested with main rotor blade data, and $H_0(6)$ will be tested with swashplate drive link data. Table 37 shows the smallest ΔS_x selected. Sample Calculation 2 is similar to that previously shown (Reference 8).

TABLE 36. EVALUATION OF $\Delta\bar{x}$ FOR CALCULATED COMPONENT DAMAGE

	(1) SIRS Spectrum	(2) Recorder Spectrum	(3) Logbook Spectrum	(2)-(3) Absolute Value	(1)-(3) Absolute Value	(1)-(2) Absolute Value
Main Rotor Blade	0.01041	0.04386	0.08491	0.04105	0.0745	0.03345
Main Rotor Yoke Extension	0.000594	0.01462	0.02833	0.01371	0.027736	0.014026
Main Rotor Grip	0.01106	0.00514	0.00910	0.00396	0.00196	0.00592
Main Rotor Pitch Horn	0.00023	0.00779	0.01379	0.006	0.10356	0.00327
Retention Strap Ftg/Nut	0.03272	0.02338	0.04137	0.01799	0.00865	0.00934
Swashplate Drive Link	0.00020	0.00468	0.00828	0.0036	0.00808	0.00448
Swashplate Outer Ring	0.01870	0.01559	0.02758	0.01199	0.00888	0.00311
Swashplate Inner Ring	0.00320	0.01694	0.02923	0.01229	0.02603	0.01374
Hydraulic Boost Cylinder	0.00037	0.01462	0.02830	0.01368	0.02793	0.01425
Tail Rotor Blade	0.02723	0.05080	0.08771	0.03691	0.06048	0.02357

TABLE 37. EVALUATION OF ΔS_x FOR CALCULATED COMPONENT DAMAGE

	(1) SIRS Spectrum	(2) Recorder Spectrum	(3) Logbook Spectrum	(2)-(3) Absolute Value	(1)-(3) Absolute Value	(1)-(2) Absolute Value
Main Rotor Blade	0.01139	0.02679	0.01206	0.01473	0.00067	0.0154
Main Rotor Yoke Extension	0.01314	0.00893	0.00400	0.00493	0.00914	0.00421
Main Rotor Grip	0.02957	0.00317	0.00177	0.0014	0.0278	0.0264
Main Rotor Pitch Horn	0.00091	0.00480	0.00269	0.00211	0.00178	0.00389
Retention Strap Ftg/Nut	0.1732	0.01439	0.0080[illegible]	0.00632	0.00925	0.00293
Swashplate Drive Link	0.00081	0.00288	0.00161	0.00127	0.0008	0.00207
Swashplate Outer Ring	0.06998	0.00960	0.00538	0.00422	0.0646	0.06038
Swashplate Inner Ring	0.00709	0.00992	0.00432	0.0056	0.00277	0.00283
Hydraulic Boost Cylinder	0.00035	0.00893	0.00402	0.00491	0.00367	0.00858
Tail Rotor Blade	0.04352	0.02976	0.01296	0.0168	0.03056	0.01376

<u>Sample Calculation 2</u>

$N_1 = 11$ $\qquad$ $N_2 = 11$

$\bar{x}_1 = 0.01139$ $\qquad$ $\bar{x}_2 = 0.01206$

$S_{\bar{x}_1} = 0.00343$ (Std. Error) $\qquad$ $S_{\bar{x}_2} = 0.00364$ (Std. Error)

$V_1 = 0.00001176$ $\qquad$ $V_2 = 0.0000132496$

$$S^2_{\bar{x}_1 - \bar{x}_2} = \frac{[(N_1 - 1)V_1 + (N_2 - 1)V_2](N_1 + N_2)}{N_1\, N_2(N_1 + N_2 - 2)}$$

$$= \frac{[10(0.00001176) + 10(0.0000132496)](22)}{121(20)}$$

$$= \frac{(0.0001176 + 0.000132496)22}{2420}$$

$$= \frac{(0.000250096)22}{2420}$$

$$= 0.000022736$$

$$t(\text{empirical}) = \frac{(0.01139 - 0.01206)}{2.2736 \times 10^{-6}}$$

$$= \underline{\underline{-294.68}}$$

n (degrees of freedom) = $N_1 + N_2 - 2 = 11 + 11 - 2 = 20$

t (at 5-percent significance) = 2.086

Since t(empirical) >> t(required at 5-percent significance), null hypothesis is rejected.

In summary, $H_0(1)$, $H_0(2)$, $H_0(3)$, $H_0(4)$, $H_0(5)$, and $H_0(6)$ are rejected at the 5-percent level of significance. This means that the deltas are due to a systematic assignable difference and cannot be attributed to a random phenomenon. The relationships of each technique to the implied service lives of these high-value, fatigue-sensitive assemblies may be observed in Figures 34 through 43.

It will be noted that the "greater than" ogives used in the figures imply a normal distribution. In an attempt to determine whether a normal distribution represented a good fit for a given data, normal curve graph paper was used to check closeness of fit on four randomly selected samples of the SIRS data. The plotted points fell reasonably close to a straight line. Hence the data was treated as normally distributed for purposes of the preliminary evaluation.

The means for each type of failure calculation are significantly different. The standard deviations for each type of failure calculation are significantly different. The standard deviations found for the SIRS throughout this test series must be considered marginally satisfactory.

Software

Three software concepts were open for evaluation during the IOT&E. The IPS, FDAS, and CMTS require close examination prior to a SIRS deployment decision. The IPS and FDAS were both exercised with satisfactory results. The CMTS remains untested in the IOT&E environment.

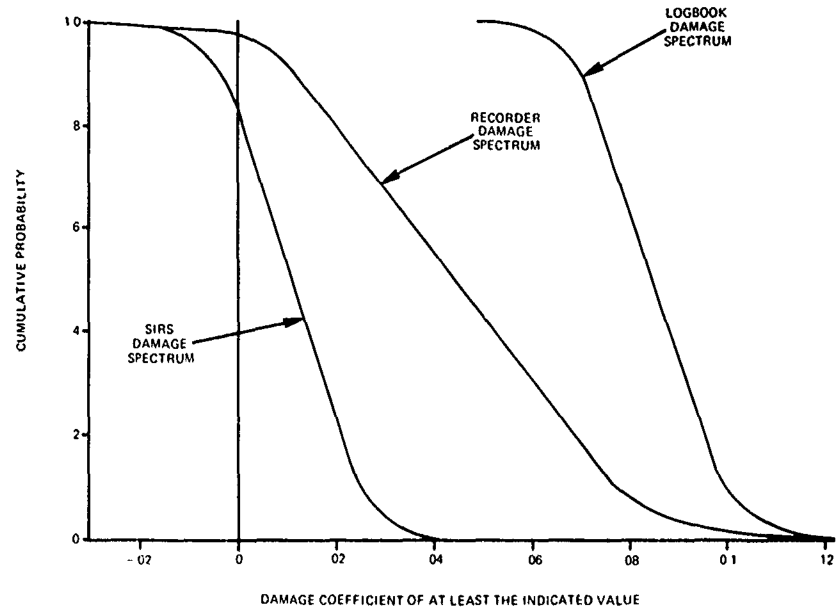


Figure 34. Main Rotor Blade Damage Spectrums.

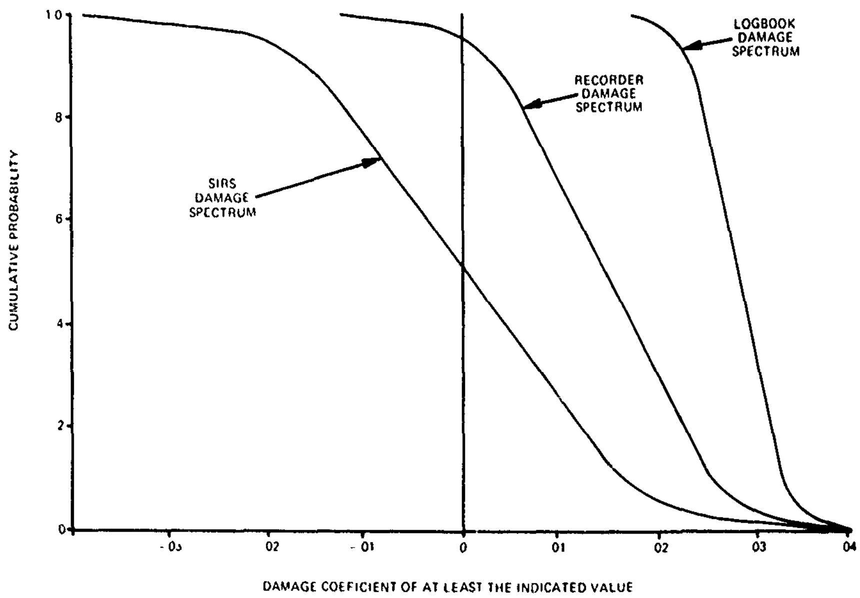


Figure 35. Main Rotor Yoke Extension Damage Spectrums.

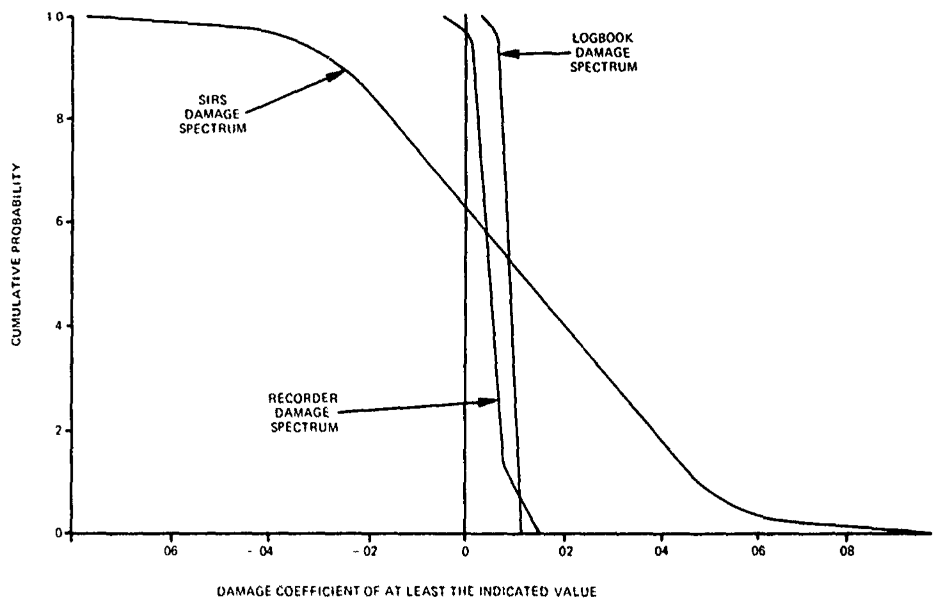


Figure 36. Main Rotor Grip Damage Spectrums.

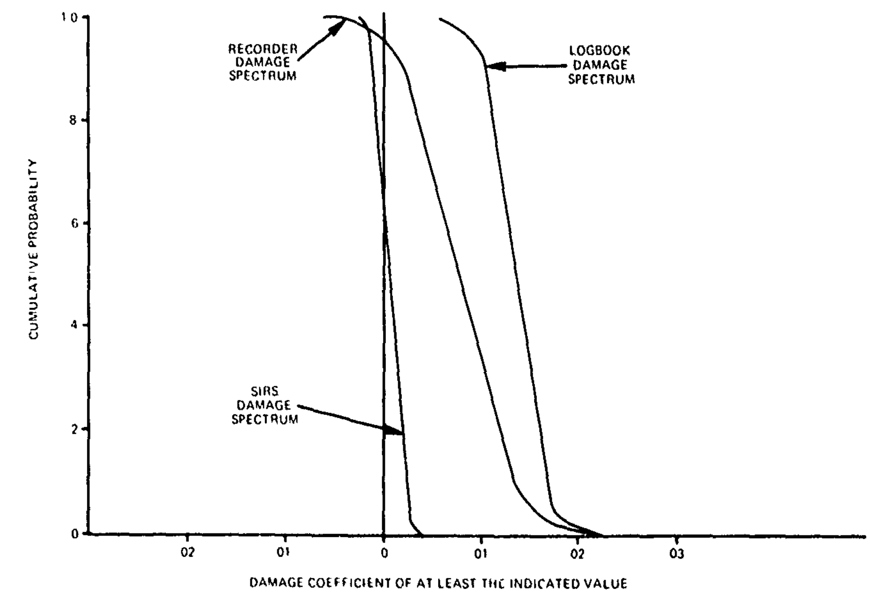


Figure 37. Main Rotor Pitch Horn Damage Spectrums.

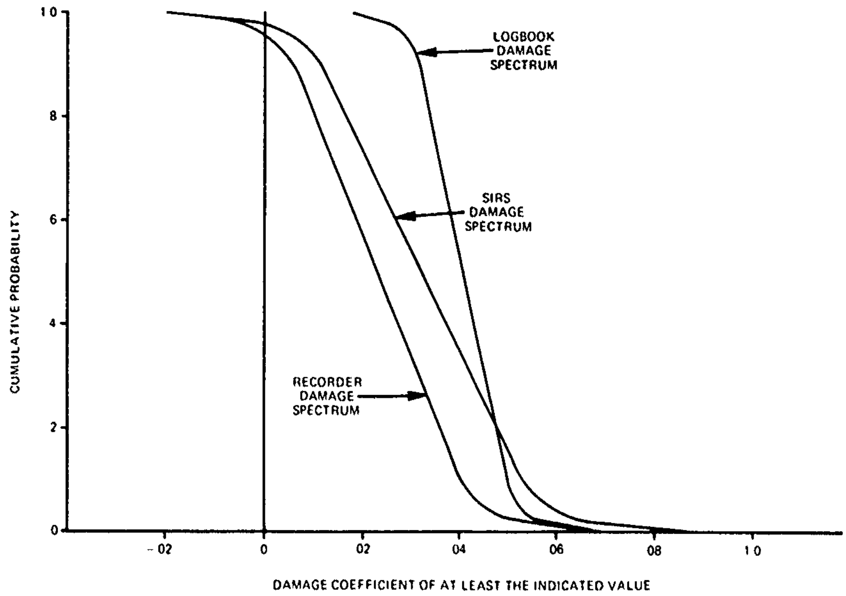


Figure 38. Retention Strap Fitting/Nut Damage Spectrums.

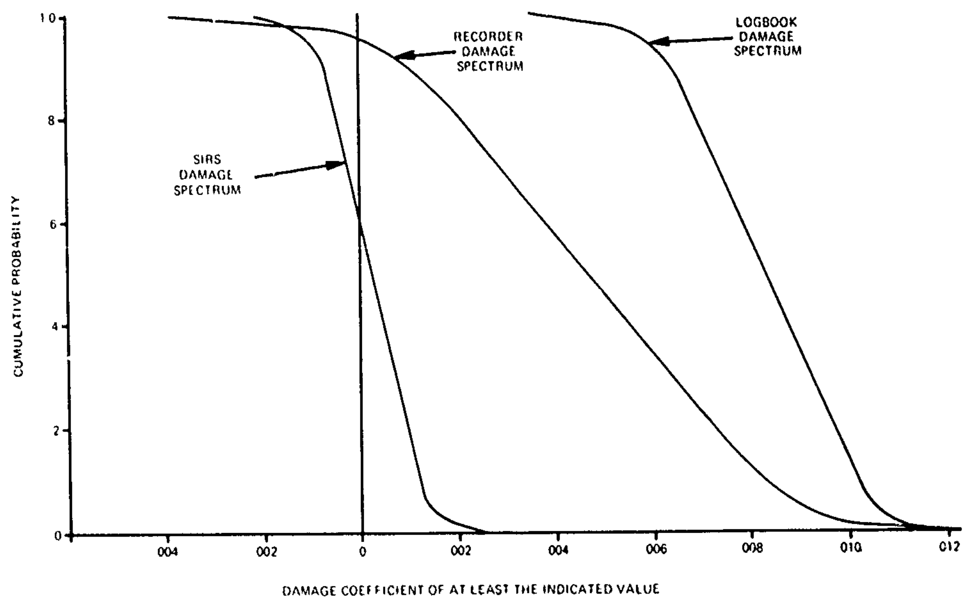


Figure 39. Swashplate Drive Link Damage Spectrums.

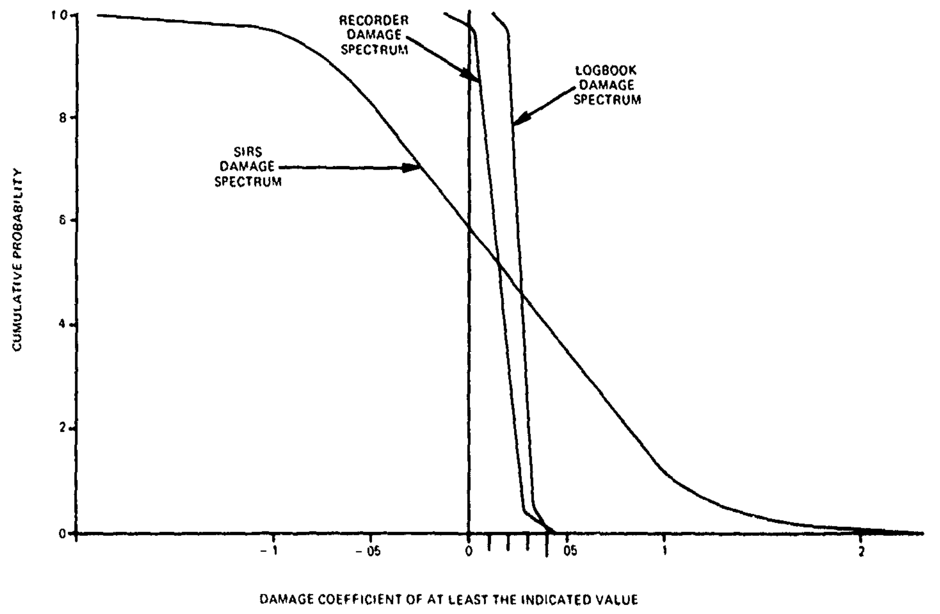


Figure 40. Swashplate Outer Ring Damage Spectrums.

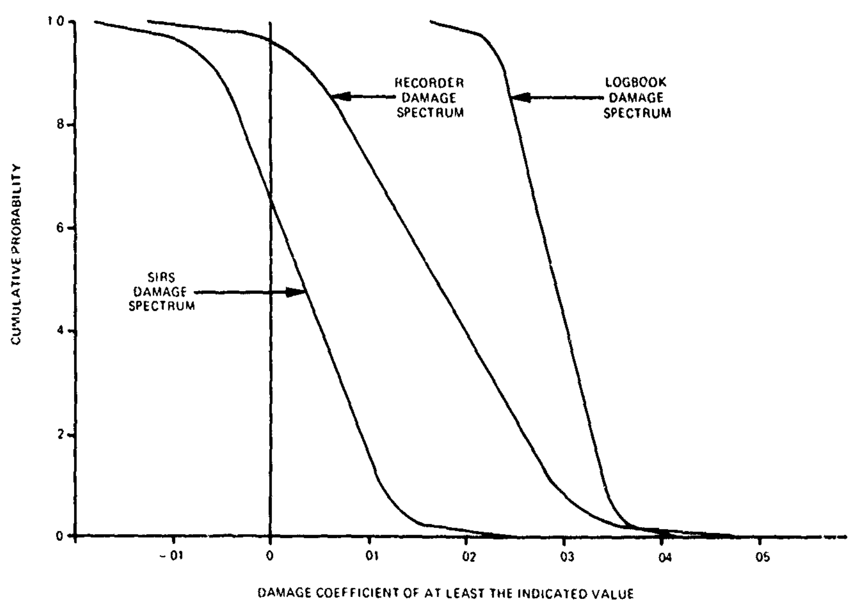


Figure 41. Swashplate Inner Ring Damage Spectrums.

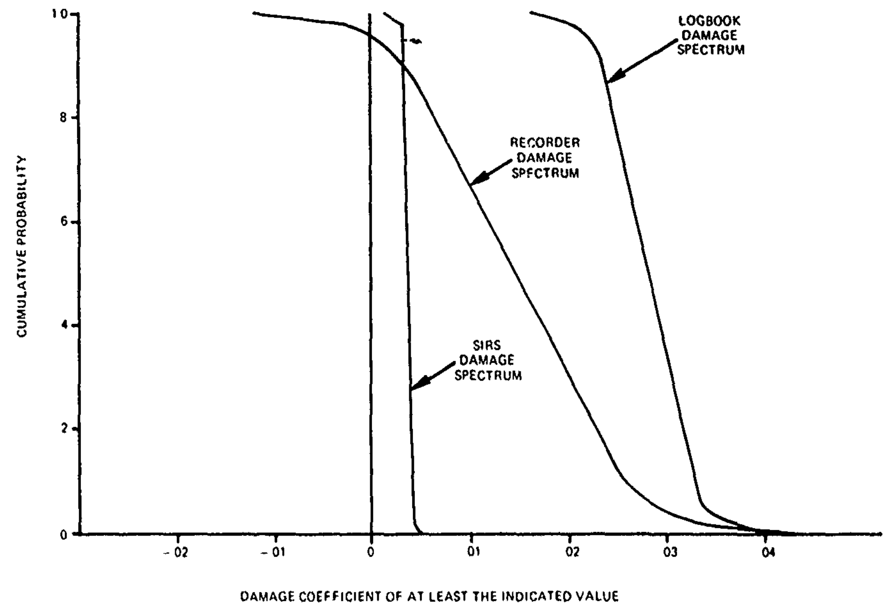


Figure 42. Hydraulic Boost Cylinder Damage Spectrums.

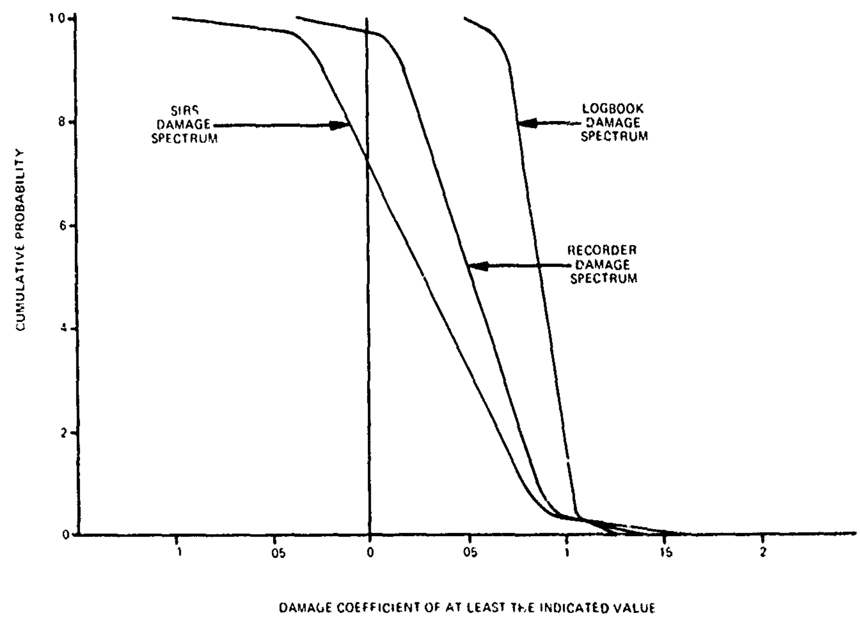


Figure 43. Tail Rotor Blade Damage Spectrums.

CHAPTER 6.

CONCLUSIONS

DT&E FLIGHT TEST (PHASE I PROTOTYPE FLIGHT TEST)

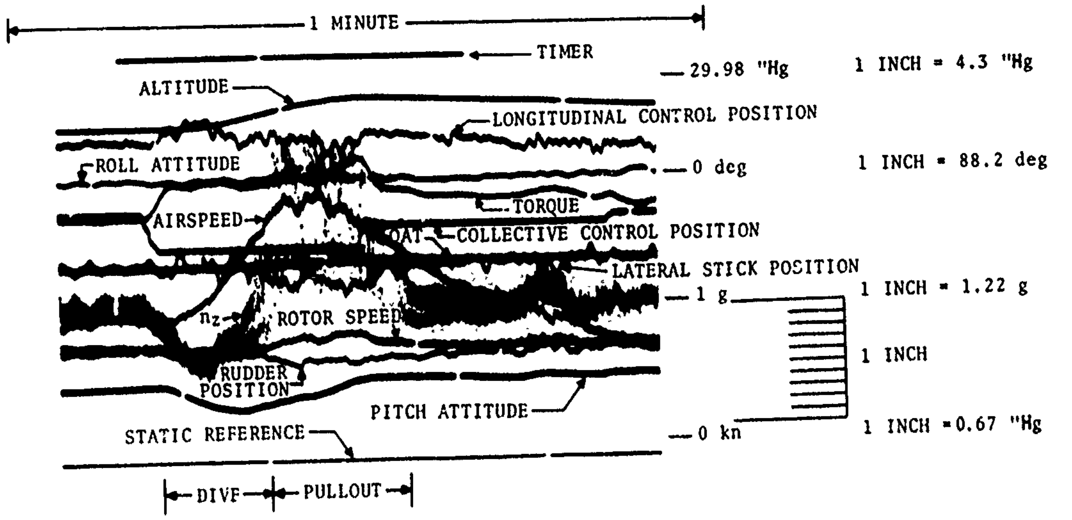
Software Modifications

Of the seven modifications identified, two have already been discussed, i.e., normal versus autorotational landing and maximum V_L detection. The logic change for measuring autorotative time was required because the software had a design error. That is, the logic included a timer designed to filter transients from the torque transducer output, but the logic did not properly clear this timer, thereby causing random amounts of time to be put into this flight condition category whenever a transient occurred. For the full-power climb condition, additional memory was allocated to permit recording both low-speed and high-speed climbs at high power settings. A minor change was made to the software, defining a Quick Stop so that the airspeed would have to decrease during the maneuver before it could be recorded.

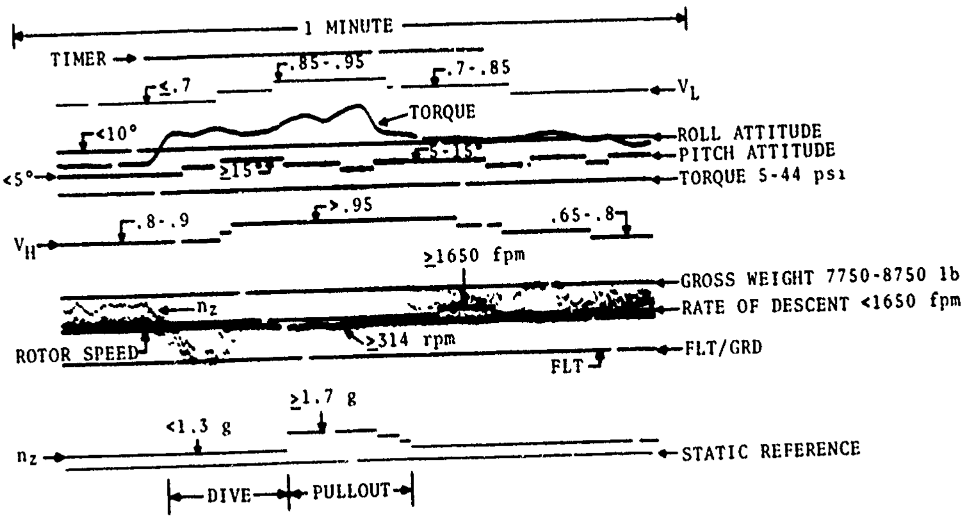
During the flight test program, numerous dives and corresponding pullouts were performed, but very little time was recorded by the SIRS recorder in either type of flight condition. In most instances, the logic relationships between rate of descent, airspeed, and vertical acceleration did not correlate with the actual relationships. A review of the data collected during the various symmetrical and asymmetrical dives and the resulting pullouts, such as the example shown in Figure 44, led to a simple method for identifying the dives. The SIRS recorder logic now "looks for" a negative vertical acceleration greater than 0.8g followed by a positive vertical acceleration of 1.3g or greater; during this interval, the airspeed must increase and the altitude must decrease by certain prescribed amounts. The dive is then categorized by the gross weight, airspeed, and vertical acceleration levels once it has been determined to be a symmetrical or asymmetrical (roll attitude outside of threshold) dive. The resulting pullout from a dive is defined as the duration that the vertical acceleration is between 1.3g and 1.1g; it is categorized by airspeed, gross weight, and its symmetrical or asymmetrical configuration.

Hardware Modifications

An alternate gross weight monitoring approach that measures gross weight in flight was identified during a joint in-house investigation conducted by Bell Helicopter Textron and Technology Incorporated. This system would measure the axial load within the lift link, a transmission mounting member. Such a system



(a) FCR Oscillograph



(b) Flag Oscillograph

Figure 44. Dive/Dive Pullout.

would update the aircraft gross weight of the helicopter whenever the helicopter is in level, unaccelerated flight. Consequently, this system would measure the gross weight more accurately than the skid landing gear technique because it could detect gross weight changes due to weapons firing.

IOT&E (PHASE II OPERATIONAL EVALUATION)

Explicit Determination of Gross Weight

During the DT&E and IOT&E program two procedures were evaluated to explicitly measure the GW parameter during flight operations of the AH-1G. One was found to be marginally satisfactory from a technical standpoint (DT&E). Both were unsatisfactory from an operational standpoint (IOT&E).

It must be recognized that the GW parameter is important in calculating fatigue lives of the 10 selected parts. However, it is additionally recognized that explicit measurement of this parameter comprises a state-of-the-art challenge. In addition, explicit measurement will be expensive. A fresh look at the problem is in order.

A cursory examination of the fatigue life calculations and the recommended service lives of the 10 selected parts implies a large error budget. This is not surprising due to the empirical nature of the phenomena. It is suggested that within the existing error budget, the GW parameter could be imputed with *a priori* knowledge of the part usage. Finally, all possible instrumentation options should be considered if explicit GW measurement is essential.

Tracking of High-Value, Fatigue-Sensitive Parts

The need for a simple, effective parts tracking procedure for the many high-value, fatigue-sensitive parts under surveillance by the SIRS concept became apparent during this short IOT&E flight test program. In addition, the process must minimally impact the logistics support of the U.S. Army aviation program.

DTU Packaging

The reported unwieldy nature of the DTU package was noted during this brief IOT&E flight test program. This package requires more in-depth evaluation. A number of alternate DTU packaging concepts could be postulated; for example, a two-package concept with rugged elements in one box and the more sensitive elements in another.

DTU Tape Drive

The selected design concept using a single capstan controller was found to be operationally inadequate and demanded

corrective action. The tape drive vendor was contacted on this matter. It was determined that an applicable cure would be to adjust the design, providing for dual-direction capstan controllers and thus ensuring positive authority over the operation of the tape location at all times. This would enable effective data manipulation and reference in a time-efficient manner.

Use of DTU During Battery Charging Operation

The inoperability of the DTU during battery charging operations was noted. The adverse impact on productivity was deemed unnecessary since a relatively minor design adjustment would readily render the DTU available for other tasks during DTU battery charging operations.

Logistics of Data Reduction

The time invested in this short IOT&E was inadequate to completely or accurately assess the logistics of the original SIRS data reduction concept.

Statistical Evaluation of Calculated Component Damage

The test results of Chapter 4 and findings reported in Chapter 5 demonstrate that the method selected to calculate service lives of the 10 selected assemblies significantly influences the economics of AH-1G life-cycle cost for those parts.

Use of logbook data to calculate component fatigue damage produces an extravagant replenishment spares requirement.

Use of recorder data to calculate component fatigue damage will yield a significantly more economical approach to logistical support of the 10 parts under consideration. This is attributed to the fact that the recorder electronics only count fatigue-damaging phenomena beginning after rotor start. Engine run time and mission planning times, for example, are not included in calculations. Thus it may be concluded that the Army might consider a counting device (recorder values) rather than operational logbook times to arrive at component retirement lives.

The optimum service life for the 10 high-value, fatigue-sensitive parts was yielded by SIRS spectrum monitoring.

Finally, it must be concluded that the scatter of SIRS component damage data during this brief IOT&E is systematic. Examination revealed a single-point failure mechanism within the recorder; i.e., the GW sensor channel was multiplexed such that it affected all other channels. Further, the GW sensor was quite troublesome throughout the IOT&E as reported in Chapter 4. Thus SIRS performance will be significantly enhanced by implementing corrective action on the GW sensing channel and the recorder multiplexing scheme.

Software

Since the IPS and FDAS have been demonstrated and found to be satisfactory, they are considered ready for OT&E testing. It is noted that the CMTS package remains untested in the DT&E and IOT&E mode.

CHAPTER 7.

RECOMMENDATIONS

As a result of the DT&E and IOT&E flight testing, several modifications of the SIRS concept are recommended. These recommendations include software logic changes to better identify certain flight conditions and hardware modifications to better survive the operational environment. In addition, operational considerations are recommended.

DT&E FLIGHT TEST (PHASE I PROTOTYPE FLIGHT TEST)

Software Modifications

A total of seven needed software changes that were recommended were made to the SIRS recorder logic and tested in the laboratory on a SIRS recorder simulator. No further action is required on this recommendation.

Hardware Modifications

As a result of the qualification program, several hardware modifications were recommended for incorporation into the recorders to be used during the Phase II Operational Evaluation. These modifications include the improvement of some of the internal wire routing and terminations. In addition, the lithium battery that failed during the temperature-altitude-humidity test was replaced by an improved, qualified lithium battery. No retesting was contemplated since this battery has been successfully tested under similar environmental conditions.

Flight testing on a Bell Model 212 helicopter equipped with both a SIRS recorder and a magnetic tape instrumentation system indicated that the in-flight gross weight measuring system would yield valid data if the center-of-gravity excursions were not large. Because the c.g. excursion on operational AH-1G helicopters is about 5 inches for gross weights ranging between 7000 and 9500 pounds, it was felt that the lift link measurement system could be adjusted for these excursions. Moreover, this system would yield data more accurately than the skid landing gear system since the latter has the limitation of an assumed fuel burn-off rate and a fixed weight for all weapons configurations.

All of these recommended alterations were executed and were successful except for the GW sensing scheme. Details of those results are cited under the IOT&E flight test program findings (Chapter 5).

IOT&E (PHASE II OPERATIONAL EVALUATION)

Explicit Determination of Gross Weight

Since the two sensor techniques selected to explicitly measure GW were unsatisfactory, a new approach is recommended for determining this important parameter. The scheme should conform to the error budget existing within the theoretical calculated fatigue life and recommended service lives of the 10 parts under evaluation in the SIRS program. In addition, a clamped-on, piezoelectric strain gage approach should be used for instrumenting the AH-1S lift link. This will eliminate the need to mechanically bond the sensor to the shot-peened lift link surface. Thorough concept testing by follow-on IOT&E with confirmed, satisfactory results prior to implementation/deployment is recommended.

Tracking of High-Value, Fatigue-Sensitive Parts

As the DT&E program merged into the IOT&E program the importance of tracking the high-value, fatigue-sensitive parts under SIRS surveillance became unmistakable. It is recommended that the SIRS DTU be modified to provide for operator inputs when a part is changed. This will minimize the need for additional paperwork at the organizational level while capturing this vital data essential to operational utility of SIRS. This concept should be tested and evaluated via a follow-on IOT&E, with using command and logistical command inputs to the evaluations.

DTU Packaging

The reported unwieldy nature of the DTU packaging should be investigated within the operational environment. The selected design is inconvenient to the operator from the standpoint of transportation. Nevertheless, execution of alternative packaging concepts entails life-cycle-cost implications. Further IOT&E of the DTU packaging should be accompanied by a cost-benefit evaluation of postulated alternatives.

DTU Tape Drive

The single DTU tape drive capstan control concept required rectification. The appropriate corrective action was to provide for dual wind/rewind capstan controllers. This recommendation was implemented and was subsequently found to be satisfactory. The DTU employed in the follow-on IOT&E flight test program of AH-1S employs this design concept. No further action is required.

Use of DTU During Battery Charging Operation

It is recommended that the DTU circuitry be redesigned to provide for operability during the battery recharging operation and that the redesign be evaluated during follow-on IOT&E.

Logistics of Data Reduction

The postulated data processing system in support of the SIRS concept was inadequately tested or evaluated due to the compressed time schedule. Complete and thorough testing and evaluation of the system via an appropriate extension of the IOT&E period is recommended. The IPS, FDAS, and CTMS should be closely examined as an integral part of the AVSCOM RAMMIT system.

Statistical Evaluation of Calculated Component Damage

The use of operational logbook hours to calculate component fatigue damage for high-value, fatigue-sensitive assemblies yields extravagant results. It is recommended that SIRS be used to compute service lives of these parts.

Since the standard deviations of SIRS results can be reduced by altering the GW sensor methodology and recorder multiplexing scheme, these changes should be implemented.

The alterations should be carefully and adequately tested via a follow-on IOT&E. Assessments by using command and logistical command should be provided prior to a deployment decision.

Software

The IPS and FDAS packages are operational. The CMTS concept should be reviewed to ensure its capability with U.S. Army aviation program needs.

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ABBREVIATIONS

ATR	Airborne Transmitter Rack
BIT	Built-In Test
CTMS	Component Tracking Management System
DoD	Department of Defense
DT&E	Development Test and Evaluation
DTU	Data Transfer Unit
EMI	Electromagnetic Interference
EMC	Electromagnetic Compatability
EPROM	Erasable Programmable Read-Only Memory
FCC	Flight Condition Category
FCM	Flight Condition Monitoring
FCR	Flight Condition Recognition
FDAS	Fatigue Damage Assessment System
GW	Gross Weight
H-GW	High Gross Weight
IOT&E	Initial Operational Test and Evaluation
IPS	Initial Processing System
L-GW	Light Gross Weight
M-GW	Medium Gross Weight
MTBF	Mean-Time-Between-Failures
O&S	Operating and Support
PC	Printed Circuit
R&D	Research and Development
RAM	Random Access Memory
RAMMIT	Reliability and Maintainability Management Improvement Techniques

ABBREVIATIONS - Concluded

RJE	Remote Job Entry
SIRS	Structural Integrity Recording System
V_H	Maximum Attainable (Level Flight) Velocity
V_L	Limit Velocity

APPENDIX A

DETAILED FCM SYSTEM DESCRIPTION

This appendix describes the flight condition categories in terms of the pertinent flight parameters by indicating the criteria that govern (1) the definition and identification of each flight condition category, and (2) the requirements for monitoring the flight condition categories. These criteria are defined by sample (theoretical) time-history traces and written descriptions.

The 103 flight condition categories are summarized in Table A-1. The letters in the column entitled "Type" are defined as follows:

T = accumulated time spent in the flight condition category during a specified recording period

C = accumulated occurrences of the flight condition category during a specified recording period

M = maximum parameter magnitude during a specified recording period

N = null recording category

The system parameters, both those directly recorded and those computed, are summarized in Table A-2.

TABLE A-1. FCM SYSTEM SUMMARY

Flt. Cond. Cat. No. Gross Weight (lb) <7750	7750-8750	>8750	Parameters	Type	Thresholds
1	2	3	Clock Time	T	. . ..
	4		Rotor Speed Above or Below Threshold	C	100 RPM
5	6	7	Vertical Accel. Below Threshold A/S Below Threshold Roll Attitude Below Threshold Pitch Attitude Above Threshold Engine Torque Press. Above Threshold	T	$n_z < 1.3g$ $A/S < 0.50\ V_H$ $\beta < 10°$ $\theta \geq 15°$ $ET \geq 5$ psi
8	9	10	Engine Torque Press. Above Threshold Touchdown Occurs	C	$ET > 5$ psi . ...
11	12	13	Vertical Accel. Below Threshold A/S Between Threshold Roll Attitude Below Threshold Rate of Descent Below Threshold	T	$n_z < 1.3g$ $0.50\ V_H \leq A/S < 0.65\ V_H$ $\beta \leq 10°$ $RD < 1650$ fpm
14	15	16	Vertical Accel. Below Threshold A/S Between Threshold Roll Attitude Below Threshold Rate of Descent Below Threshold Engine Torque Press. Between Thresholds	T	$n_z < 1.3g$ $0.65\ V_H \leq A/S < 0.95\ V_H$ $\beta \leq 10°$ $RD < 1650$ fpm 5 psi $< ET \leq 44$ psi
17	18	19	Vertical Accel. Below Threshold A/S Above Threshold Roll Attitude Below Threshold Rate of Descent Below Threshold	T	$n_z < 1.3g$ $A/S \geq 0.95\ V_H$ $\beta \leq 10°$ $RD < 1650$ fpm
20	21	22	Vertical Accel. Below Threshold A/S Between Thresholds Roll Attitude Below Threshold Rate of Descent Below Threshold Engine Torque Press. Above Threshold	T	$n_z < 1.3g$ $0.50\ V_H \leq A/S < 0.65\ V_H$ $\beta \leq 10°$ $RD < 1650$ fpm $ET > 44$ psi
23	24	25	Vertical Accel. Between Threshold A/S Between Thresholds Roll Attitude Above Threshold	T	$1.3 \leq n_z < 1.5$ $0.65\ V_H \leq A/S < 0.80\ V_H$ $\beta \geq 10°$
26	27	28	Vertical Accel. Between Threshold A/S Above Threshold Roll Attitude Above Threshold	T	$1.3 \leq n_z < 1.5$ $A/S \geq 0.80\ V_H$ $\beta \geq 10°$
29	30	31	Vertical Accel. Below Threshold A/S Below Threshold Roll Attitude Below Threshold Rate of Descent Above Threshold	T	$n_z < 1.3g$ $A/S \leq 0.70\ V_L$ $\beta \leq 10°$ $RD \geq 1650$ fpm
32	33	34	Vertical Accel. Below Threshold A/S Between Thresholds Roll Attitude Below Threshold Rate of Descent Above Threshold	T	$n_z < 1.3g$ $0.70\ V_L < A/S \leq 0.85\ V_L$ $\beta < 10°$ $RD \geq 1650$ fpm
35	36	37	Vertical Accel. Below Threshold A/S Between Thresholds Roll Attitude Below Threshold Rate of Descent Above Threshold	T	$n_z < 1.3g$ $0.85\ V_L < A/S \leq 0.95\ V_L$ $\beta < 10°$ $RD \geq 1650$ fpm
38	39	40	Vertical Accel. Below Threshold A/S Above Threshold Roll Attitude Below Threshold Rate of Descent Above Threshold	T	$n_z < 1.3g$ $A/S > 0.95\ V_L$ $\beta < 10°$ $RD \geq 1650$ fpm
41	42	43	Vertical Accel. Above Threshold A/S Below Threshold Roll Attitude Between Threshold	T	$n_z \geq 1.5g$ $A/S \leq 0.70\ V_L$ $10° \leq \beta < 35°$
44	45	46	Vertical Accel. Above Threshold A/S Between Thresholds Roll Attitude Between Threshold	T	$n_z \geq 1.5g$ $0.70\ V_L \leq A/S < 0.85\ V_L$ $10° < \beta < 35°$
47	48	49	Vertical Accel. Above Threshold A/S Between Thresholds Roll Attitude Between Thresholds	T	$n_z \geq 1.5g$ $0.85\ V_L \leq A/S < 0.95\ V_L$ $10° < \beta < 35°$
50	51	52	Vertical Accel. Above Threshold A/S Above Threshold Roll Attitude Between Thresholds	T	$n_z \geq 1.5g$ $A/S \geq 0.95\ V_L$ $10° < \beta < 35°$

TABLE A-1. Concluded

Flt. Cond. Cat. No. Gross Weight (lb) <7750	7750-8750	>8750	Parameters	Type(*)	Thresholds
53	54	55	Vertical Accel. Above Threshold A/S Below Threshold Roll Attitude Below Threshold Pitch Attitude Above Threshold	T	$n_z \geq 1.3g$ $A/S \leq 0.70\ V_L$ $\beta \leq 10°$ $\theta > 5°$
56	57	58	Vertical Accel. Above Threshold A/S Between Thresholds Roll Attitude Below Threshold Pitch Attitude Above Threshold	T	$n_z \geq 1.3g$ $0.70\ V_L \leq A/S \leq 0.85\ V_L$ $\beta < 10°$ $\theta > 5°$
59	60	61	Vertical Accel. Above Threshold A/S Above Threshold Roll Attitude Below Threshold Pitch Attitude Above Threshold	T	$n_z \geq 1.3g$ $A/S \geq 0.85\ V_L$ $\beta \leq 10°$ $\theta > 5°$
62	63	64	Vertical Accel. Above Threshold A/S Below Threshold Initial Roll Attitude Above Threshold Subsequent Roll Attitudes Below Threshold	T	$n_z \geq 1.5g$ $A/S \leq 0.65\ V_H$ $\beta \geq 35°$ $\beta \leq 25°$
65	66	67	Vertical Accel. Above Threshold A/S Between Thresholds Initial Roll Attitude Above Threshold Subsequent Roll Attitudes Below Threshold	T	$n_z \geq 1.5g$ $0.65\ V_H \leq A/S \leq 0.80\ V_H$ $\beta > 35°$ $\beta \leq 25°$
68	69	70	Vertical Accel. Above Threshold A/S Above Threshold Initial Roll Attitude Above Threshold Subsequent Roll Attitudes Below Threshold	T	$n_z \geq 1.5g$ $A/S \geq 0.80\ V_H$ $\beta > 35°$ $\beta \leq 25°$
71	72	73	Vertical Accel. Above Threshold A/S Below Threshold Initial Roll Attitude Above Threshold Subsequent Roll Attitude Above Threshold	T	$n_z \geq 1.5g$ $A/S \leq 0.90\ V_H$ $\beta \geq 35°$ $\beta \geq 25°$
74	75	76	Vertical Accel. Above Threshold A/S Above Threshold Initial Roll Attitude Above Threshold Subsequent Roll Attitudes Above Threshold	T	$n_z \geq 1.5g$ $A/S \geq 0.90\ V_H$ $\beta \geq 35°$ $\beta \geq 25°$
77	78	79	Flight Clock Time Engine Torque Press. Below Threshold	T	.... $ET \leq 5$ psi
80	81	82	Vertical Accel. Between Thresholds A/S Above Threshold Engine Torque Press. Crosses Threshold (4-6 psi)	C	$1.3 \leq n_z < 1.5$ $A/S \geq 0.65\ V_H$ 5 psi
83	84	85	Vertical Accel. Above Threshold A/S Above Threshold Engine Torque Press. Crosses Threshold (4-6 psi)	C	$n_z > 1.5$ $A/S > 0.65\ V_H$ 5 psi
86	87	88	Vertical Accel. Between Thresholds A/S Above Threshold Engine Torque Press. Below Threshold Roll Attitude Above Threshold	T	$1.3 \leq n_z < 1.5$ $A/S \geq 0.65\ V_H$ 5 psi $\beta > 10°$
89	90	91	Vertical Accel. Above Threshold A/S Above Threshold Engine Torque Press. Below Threshold Roll Attitude Above Threshold	T	$n_z > 1.5g$ $A/S > 0.65\ V_H$ 5 psi $\beta \geq 10°$
92	93	94	Engine Torque Press. Below Threshold Touchdown Occurs	C	5 psi ....
	95		Vertical Accel. Above Threshold A/S Above Threshold	C	$n_z \geq 1.7g$ $A/S \geq 0.50\ V_H$
	96		Maximum n_z Magnitude Attained	M	....
	97		Maximum A/S Magnitude Attained	M	$A/S = f(V_L)$
98	99	100	Not Recorded Directly	N	Not Applicable
101	102	103	Not Recorded Directly	N	Not Applicable

TABLE A-2. SYSTEM PARAMETERS

System Parameters		Directly Recorded	Computed	Sign Convention for Positive Number
Indicated Airspeed	(A/S)	X		------------------
Max. Level Flight	(V_H)		$V_H = f(T, H_p)$	------------------
Limit Velocity	(V_L)		$V_L = f(t, H_p)$	------------------
Pressure Altitude	(H_p)	X		------------------
Outside Air Temperature	(T)	X		------------------
Rate of Descent	(RD)		$RD = f(H_p, \text{Time})$	Decreasing Altitude
Main Rotor Velocity	(MRV)	X		------------------
Roll Attitude	(β)	X		------------------
Pitch Attitude	(θ)	X		------------------
Vertical Acceleration	(n_z)	X		Ship Accelerates Up
Landing Gear Touchdown	(TD)	X		------------------
Engine Torque Pressure	(ET)	X		Increasing Torque
Takeoff Gross Weight	(TGW)	X		------------------
In-Flight Gross Weight	(GW)		$GW = f(TGW, \text{Time})$	------------------

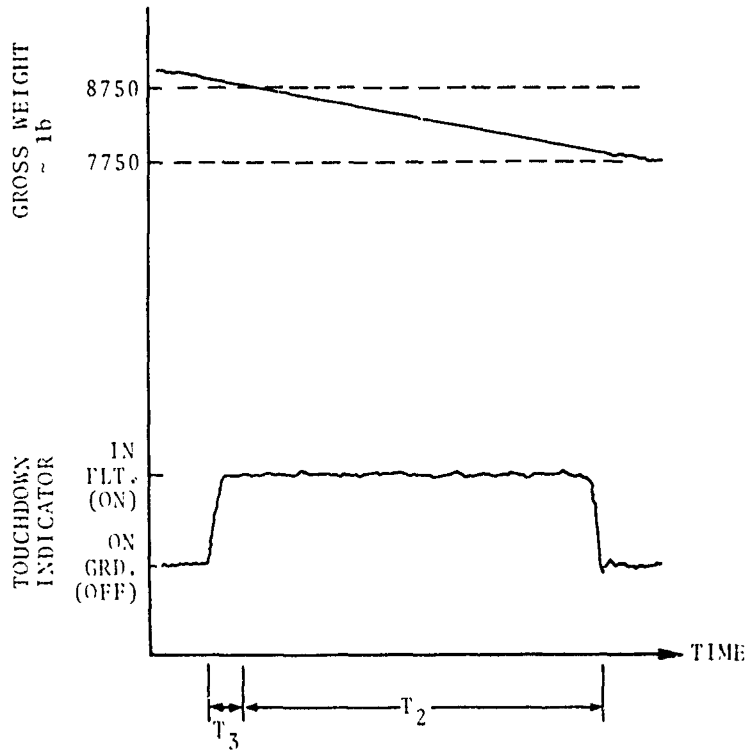
Each type of flight condition category is depicted in Figures A-1 through A-20. In examining these figures, the following statements are applicable to all flight condition categories:

1. Unless otherwise indicated, the engine torque pressure in each flight condition category must be greater than 5 psi.

2. Whenever a roll or a pitch attitude threshold is defined (e.g., $\beta > 10°$), it represents the absolute value of roll or pitch attitude (i.e., $|\beta| \geq 10°$).

Represents: Flight Clock Time

FCC Applicability	TD ON/OFF
FCC #1	GW < 7750 lb
FCC #2	7750 lb ≤ GW ≤ 8750 lb
FCC #3	GW > 8750



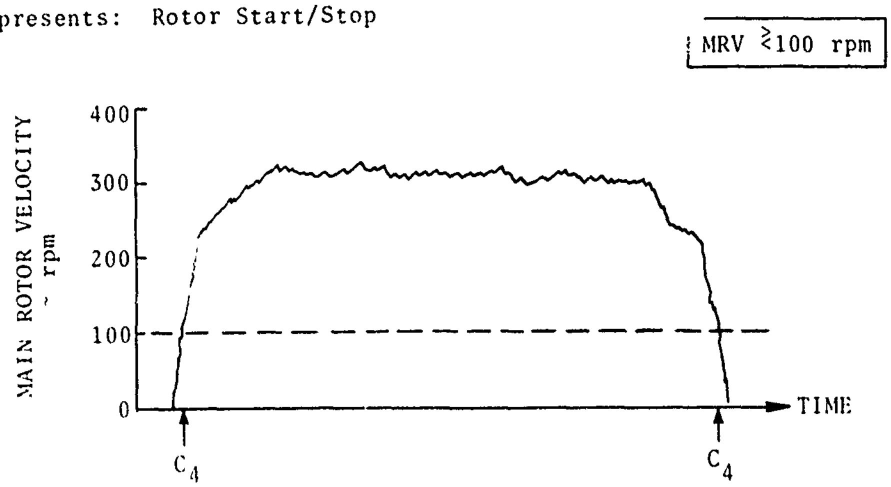
T_1 = FCC #1 Timer
T_2 = FCC #2 Timer
T_3 = FCC #3 Timer

Description

Monitor the clock time accrued by the helicopter while airborne.

Figure A-1. Flight Condition Categories 1, 2, and 3 (In-Flight Time).

Represents: Rotor Start/Stop



C_4 = FCC #4 counter

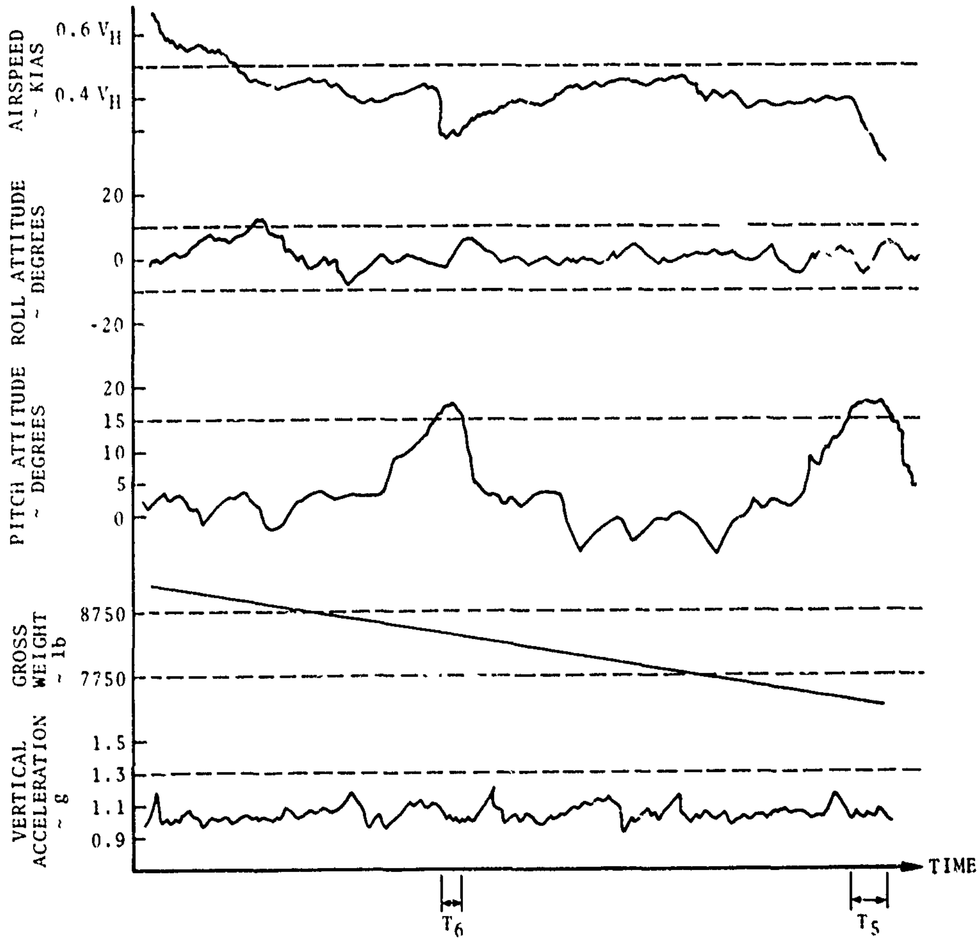
Description

Monitor the number of times the main rotor velocity passes through the 100 rpm regime. To ensure against extra C_4 counts due to small perturbations of the main rotor velocity, require that all C_4 events must occur at least 10 seconds apart.

Figure A-2. Flight Condition Category 4 (Rotor Start/Stop).

Represents: Quick-Stop Deceleration

FCC Applicability	$n_z \le 1.3g$ $A/S < 0.50\ V_H$ $\beta < 10°$ $\theta \ge 15°$ $ET > 5$ psi
FCC #5	GW < 7750 lb
FCC #6	7750 lb < GW ≤ 8750 lb
FCC #7	GW > 8750 lb



T_5 = FCC #5 Timer
T_6 = FCC #6 Timer
T_7 = FCC #7 Timer

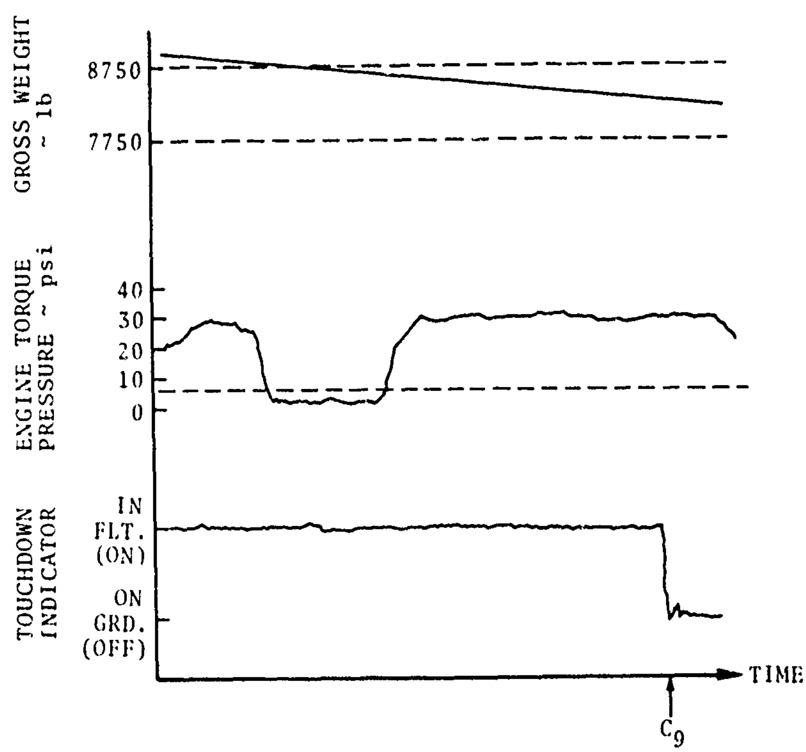
Description

Monitor the clock time accrued by the helicopter during which all six parameter threshold definitions are being satisfied simultaneously. The airspeed requirement is based on maximum attainable velocity at constant altitude (V_H), which is a function of density altitude.

Figure A-3. Flight Condition Categories 5, 6, and 7 (Quick-Stop Deceleration).

Represents: Normal Landing

FCC Applicability	ET > 5 psi TD ON/OFF
FCC #8	GW < 7750 lb
FCC #9	7750 lb < GW ≤ 8750 lb
FCC #10	GW > 8750 lb



C_8 = FCC #8 Counter
C_9 = FCC #9 Counter
C_{10} = FCC #10 Counter

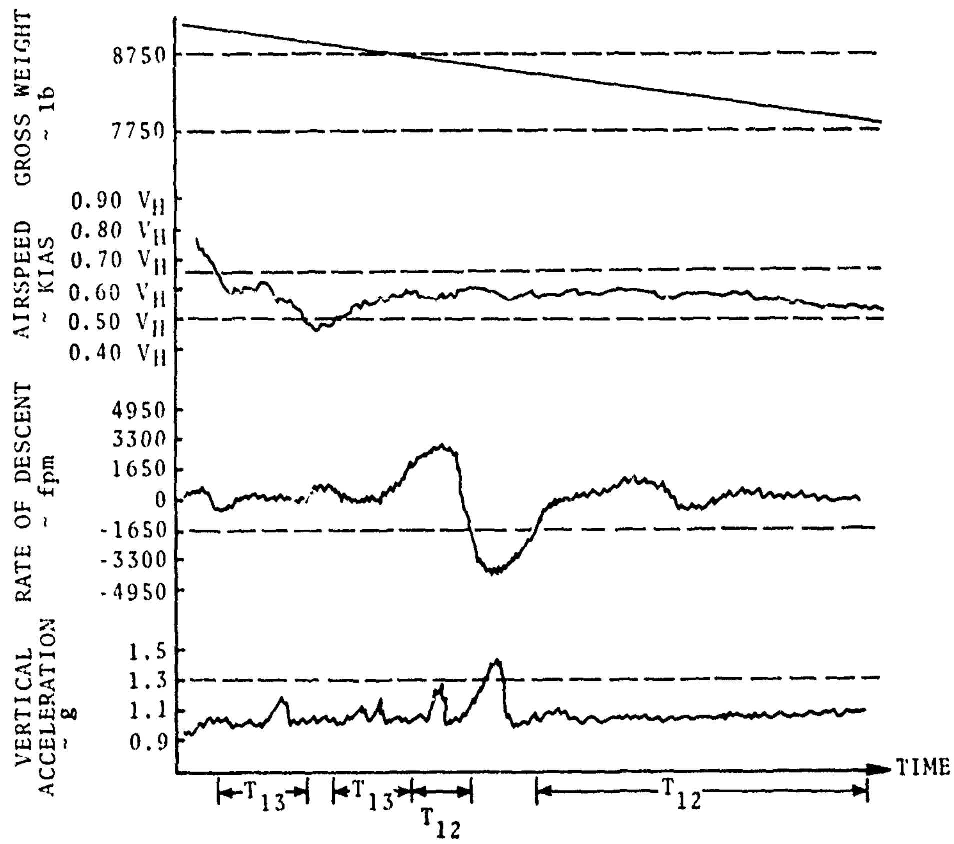
Description

The engine torque pressure must be above threshold immediately prior to (at least 10 seconds), and at the time of, touchdown. Once a touchdown has been recorded, a rebounding helicopter should not register additional counts.

Figure A-4. Flight Condition Categories 8,9, and 10 (Normal Landing).

Represents: Low-Velocity Flight Conditions
(e.g., Forward Level Flight, Normal Full Power Climbs, and Low-Speed Turns)

FCC Applicability	$n_z < 1.3g$ $0.50\ V_H \leq A/S < 0.65\ V_H$ $\beta < 10°$ $RD < 1650$ fpm
FCC #11	GW < 7750 lb
FCC #12	7750 lb ≤ GW ≤ 8750 lb
FCC #13	GW > 8750 lb



T_{11} = FCC #11 Timer
T_{12} = FCC #12 Timer
T_{13} = FCC #13 Timer

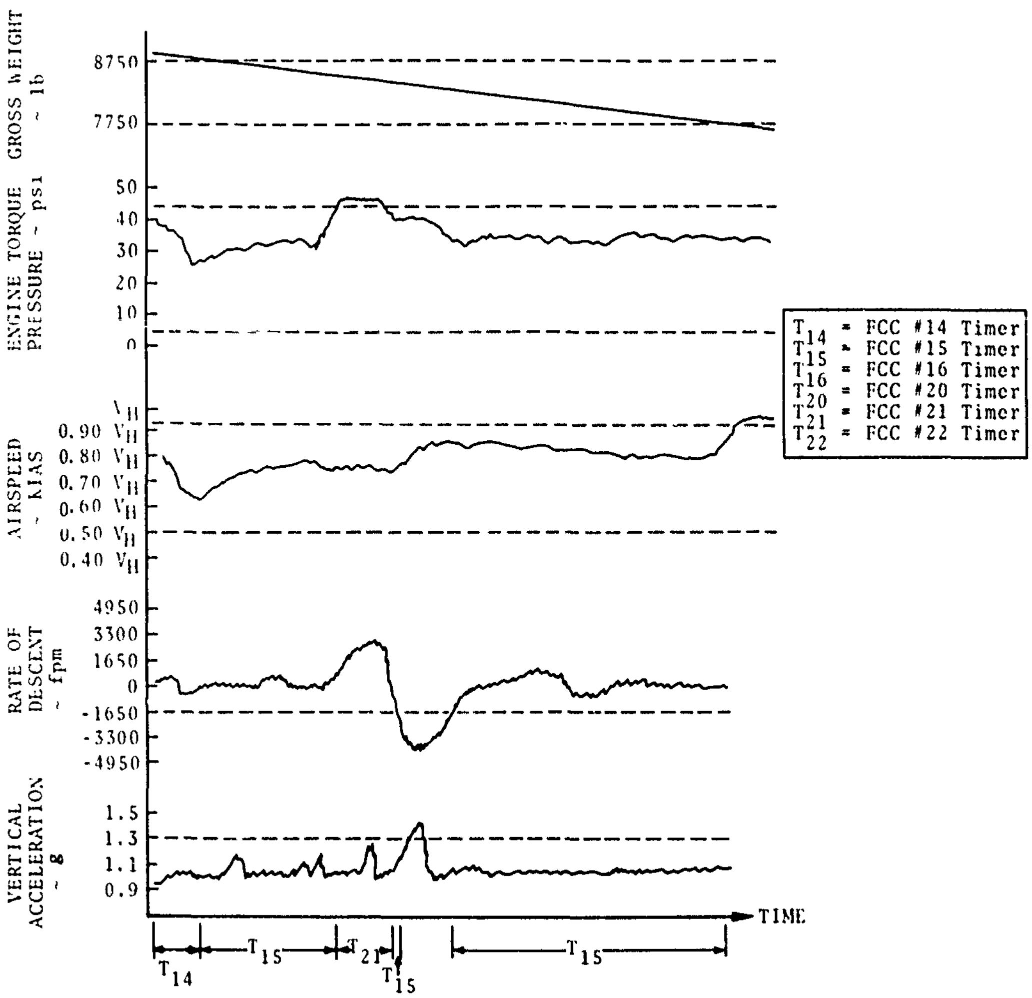
Description

Monitor the clock time accrued by the helicopter during which all five parameter threshold definitions are being satisfied simultaneously. The airspeed classification is based on maximum attainable velocity at constant altitude (V_H), which is a function of density altitude.

Figure A-5. Flight Condition Categories 11, 12, and 13 (Low-Velocity Flight).

Represents: High-Velocity Flight Conditions
(e.g., Forward Level Flight, Part Power Descent, High-Speed Control Corrections, and High-Speed Full Power Climbs)

FCC Applicability		
—For— 5<ET≤44	—For— ET>44	n_z < 1.3g 0.50 V_H ≤ A/S ≤ 0.95 V_H β < 10° RD < 1650 fpm
FCC #14	FCC #20	GW < 7750 lb
FCC #15	FCC #21	7750 lb < GW ≤ 8750 lb
FCC #16	FCC #22	GW > 8750 lb



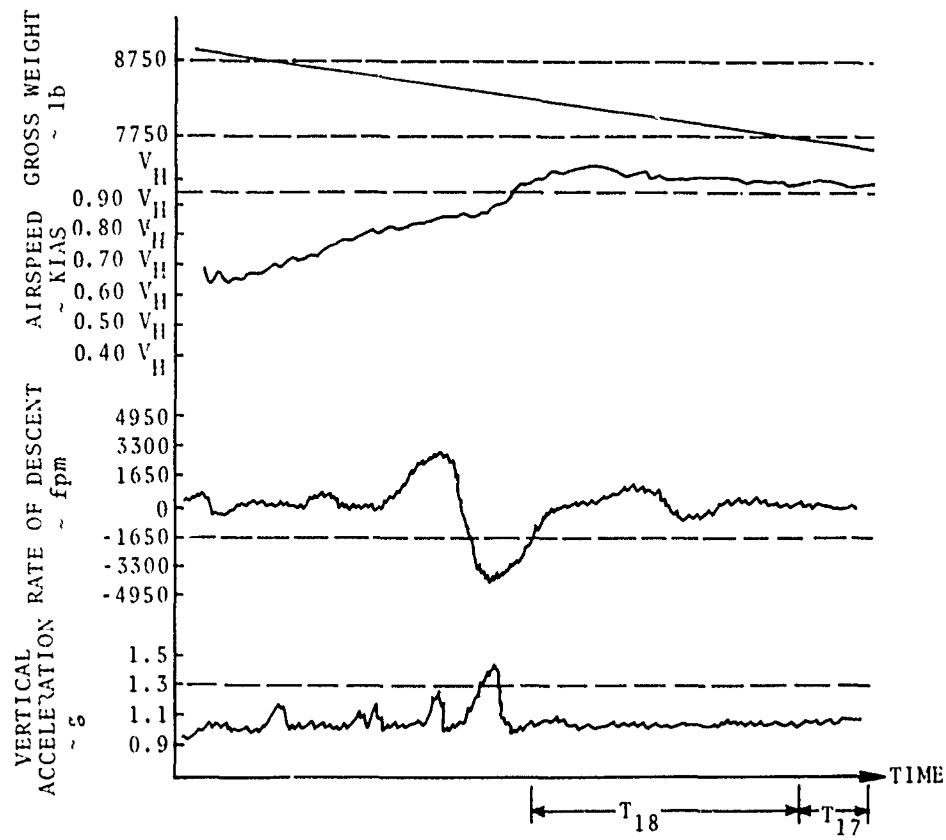
Description

Monitor the clock time accrued by the helicopter during which all six parameter threshold definitions are being satisfied simultaneously. The airspeed classification is based on maximum attainable velocity at constant altitude (V_H), which is a function of density altitude.

Figure A-6. Flight Condition Categories 14, 15, 16, 20, 21, and 22 (High-Velocity Flight).

Represents: Maximum-Velocity Flight Conditions
(e.g., Forward Level Flight)

FCC Applicability	$n_z < 1.3g$ $A/S \geq 0.95\ V_H$ $\beta < 10°$ $RD < 1650$ fpm
FCC #17	$GW < 7750$ lb
FCC #18	$7750 \text{ lb} < GW \leq 8750$ lb
FCC #19	$GW > 8750$ lb



T_{17} = FCC #17 Timer
T_{18} = FCC #18 Timer
T_{19} = FCC #19 Timer

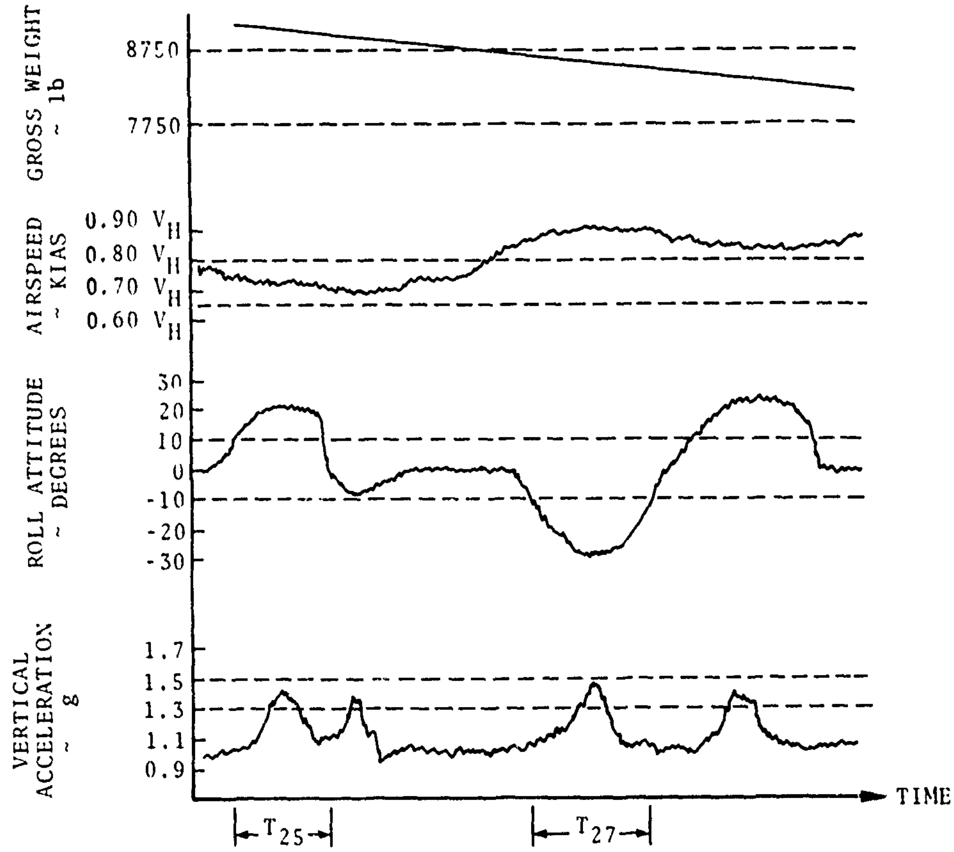
<u>Description</u>

Monitor the clock time accrued by the helicopter during which all five parameter threshold definitions are being satisfied simultaneously. The airspeed classification is based on maximum attainable velocity at constant altitude (V_H), which is a function of density altitude.

Figure A-7. Flight Condition Categories 17, 18, and 19 (Maximum-Velocity Flight).

Represents: Normal (High-Speed) Turns

FCC Applicability		
For $0.65V_H < A/S < 0.8V_H$	For $A/S \geq 0.8V_H$	$1.3g \leq n_z < 1.5g$ $\beta > 10°$
FCC #23	FCC #26	GW < 7750 lb
FCC #24	FCC #27	7750 lb < GW $\leq$ 8750 lb
FCC #25	FCC #28	GW > 8750 lb

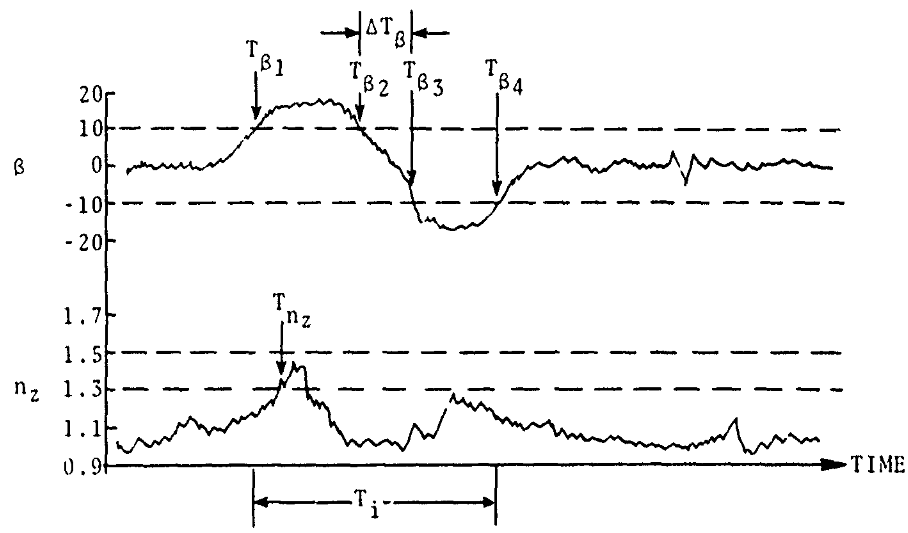


T_{23} = FCC #23 Timer
T_{24} = FCC #24 Timer
T_{25} = FCC #25 Timer
T_{26} = FCC #26 Timer
T_{27} = FCC #27 Timer
T_{28} = FCC #28 Timer

Figure A-8. Flight Condition Categories 23 through 28 (Normal (High-Speed) Turns).

Description

The following graphical characterization demonstrates how the time spent in normal turns should be defined.



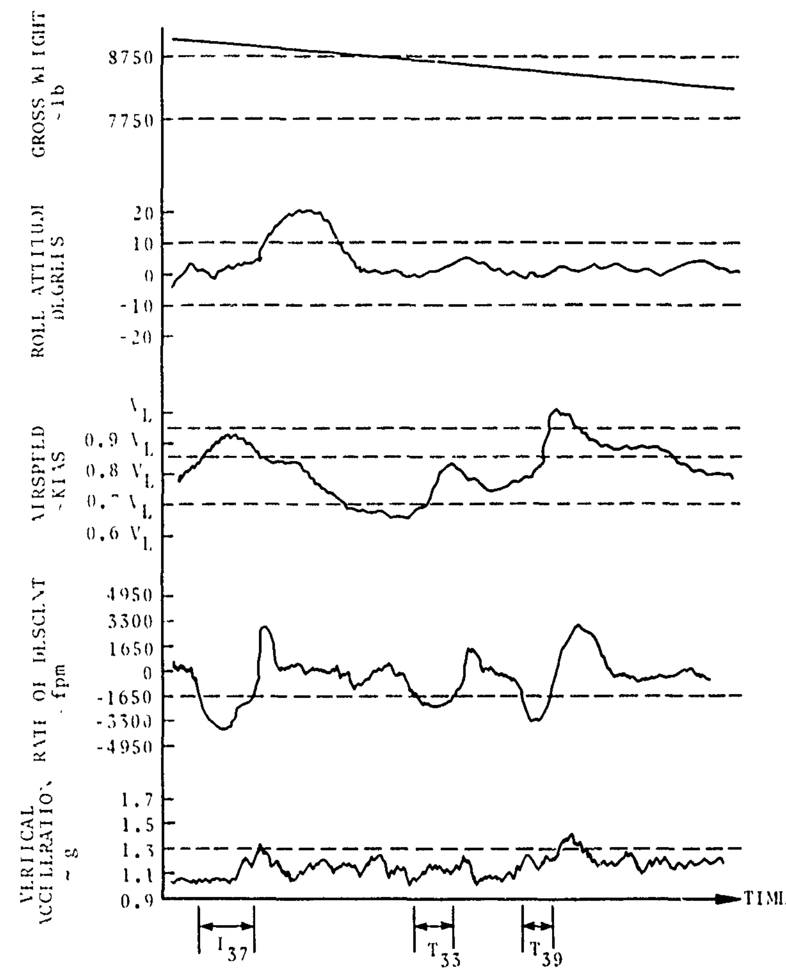
$T_{\beta 1}$ = time at which roll attitude first exceeds 10° threshold
$T_{\beta 2,3,4}$ = respective times at which roll attitude crosses 10° threshold
T_{n_z} = time at which vertical acceleration exceeds threshold
ΔT_β = time between roll attitude threshold exceedances (see figure)
T_i = normal turn occurrence timer for FCC #i, i = 23,28

The time between $T_{\beta 1}$ and T_{n_z} is defined at less than 10 seconds. Upon confirmation that the roll attitude peaks at a magnitude greater than 10° and the vertical acceleration also peaks between 1.3 and 1.5 g within the prescribed time, the timer (T_i) should be initiated at $T_{\beta 1}$. If ΔT_β is subsequently less than 10 seconds, T_i should be allowed to continue timing until the roll attitude again returns below threshold (at $T_{\beta 4}$); otherwise, terminate T_i and $T_{\beta 2}$. The airspeed classification is based on maximum attainable velocity at constant altitude (V_H) which is a function of density altitude. The airspeed categorization, for a given turn, is defined at $T_{\beta 1}$. If the gross weight classification should change during the turn, the entire T_i should be entered in the category corresponding to the greater gross weight.

Figure A-8. Concluded

Represents: Gunnery Run Dives

FCC Applicability				
For $A/S \leq 0.70V_L$	For $0.70V_L \leq A/S \leq 0.85V_L$	For $0.85V_L \leq A/S \leq 0.95V_L$	For $A/S > 0.95V_L$	
FCC #29	FCC #32	FCC #35	FCC #38	$n_z < 1.3g$ $\beta < 10°$ RD > 1650 fpm GW $\leq$ 7750 lb
FCC #30	FCC #33	FCC #36	FCC #39	7750 lb < GW $\leq$ 8750 lb
FCC #31	FCC #34	FCC #37	FCC #40	GW > 8750 lb



T_{29} = FCC #29 Timer
T_{30} = FCC #30 Timer
T_{31} = FCC #31 Timer
T_{32} = FCC #32 Timer
T_{33} = FCC #33 Timer
T_{34} = FCC #34 Timer
T_{35} = FCC #35 Timer
T_{36} = FCC #36 Timer
T_{37} = FCC #37 Timer
T_{38} = FCC #38 Timer
T_{39} = FCC #39 Timer
T_{40} = FCC #40 Timer

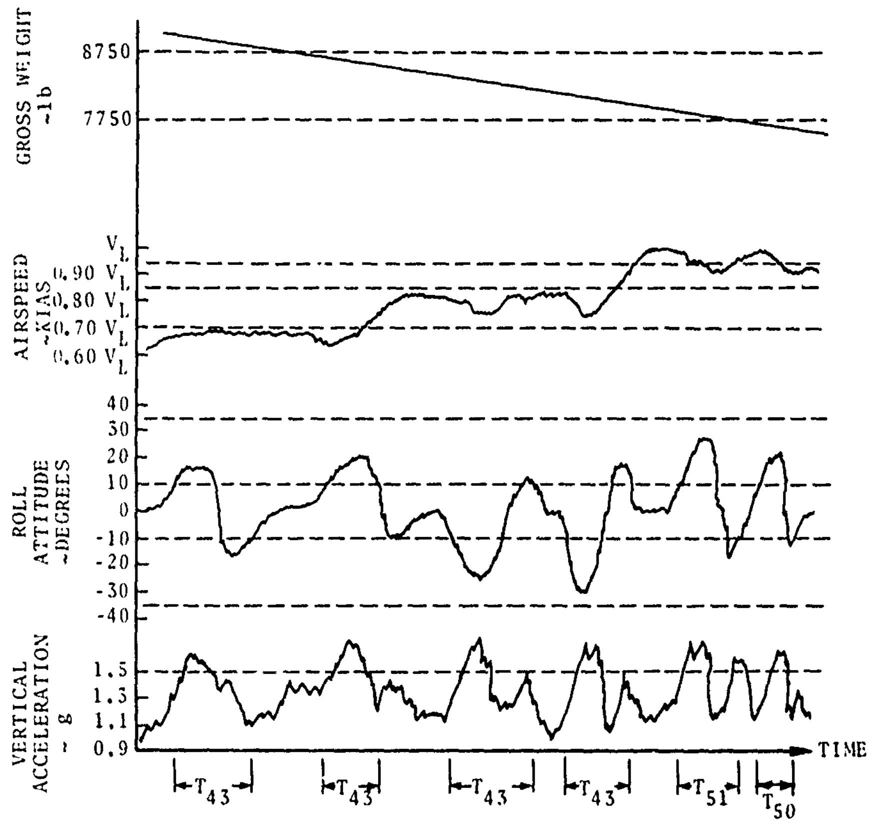
Description

Monitor the clock time accrued by the helicopter during which all parameter threshold definitions are being satisfied simultaneously. The airspeed classification is based on percentage of limit velocity (V_L), which is a function of density altitude. Airspeed is categorized near the end of the dive.

Figure A-9. Flight Condition Categories 24 through 40 (Gunnery Run Dives).

Represents: Asymmetrical Pullups

FCC Applicability				
For $A/S \le 0.70V_L$	For $0.70V_L < A/S \le 0.85V_L$	For $0.85V_L < A/S \le 0.95V_L$	For $A/S > 0.95V_L$	$n_z \ge 1.5g$, $10° < \beta < 35°$
FCC #41	FCC #44	FCC #47	FCC #50	GW < 7750 lb
FCC #42	FCC #45	FCC #48	FCC #51	7750 lb < GW ≤ 8750 lb
FCC #43	FCC #46	FCC #49	FCC #52	GW > 8750 lb



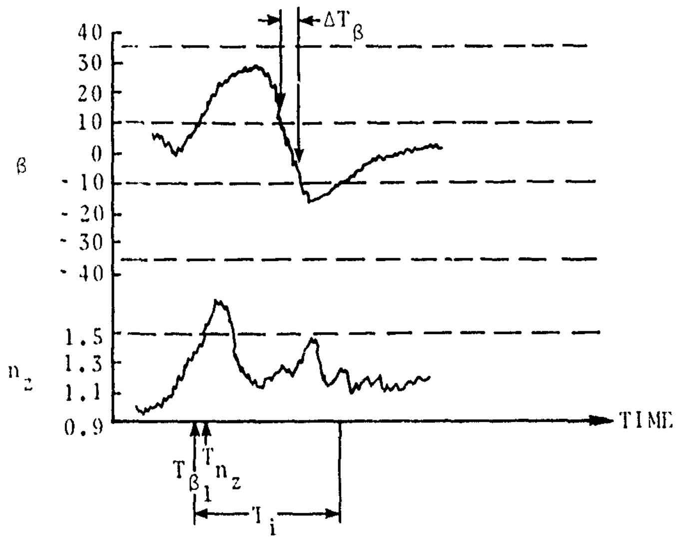
T_{41} = FCC #41 Timer
T_{42} = FCC #42 Timer
T_{43} = FCC #43 Timer
T_{44} = FCC #44 Timer
T_{45} = FCC #45 Timer
T_{46} = FCC #46 Timer

T_{47} = FCC #47 Timer
T_{48} = FCC #48 Timer
T_{49} = FCC #49 Timer
T_{50} = FCC #50 Timer
T_{51} = FCC #51 Timer
T_{52} = FCC #52 Timer

Figure A-10. Flight Condition Categories 41 through 52 (Asymmetrical (Gunnery Run) Pullups).

Description

The following graphical characterization demonstrates how the time spent in asymmetrical pullups should be defined:



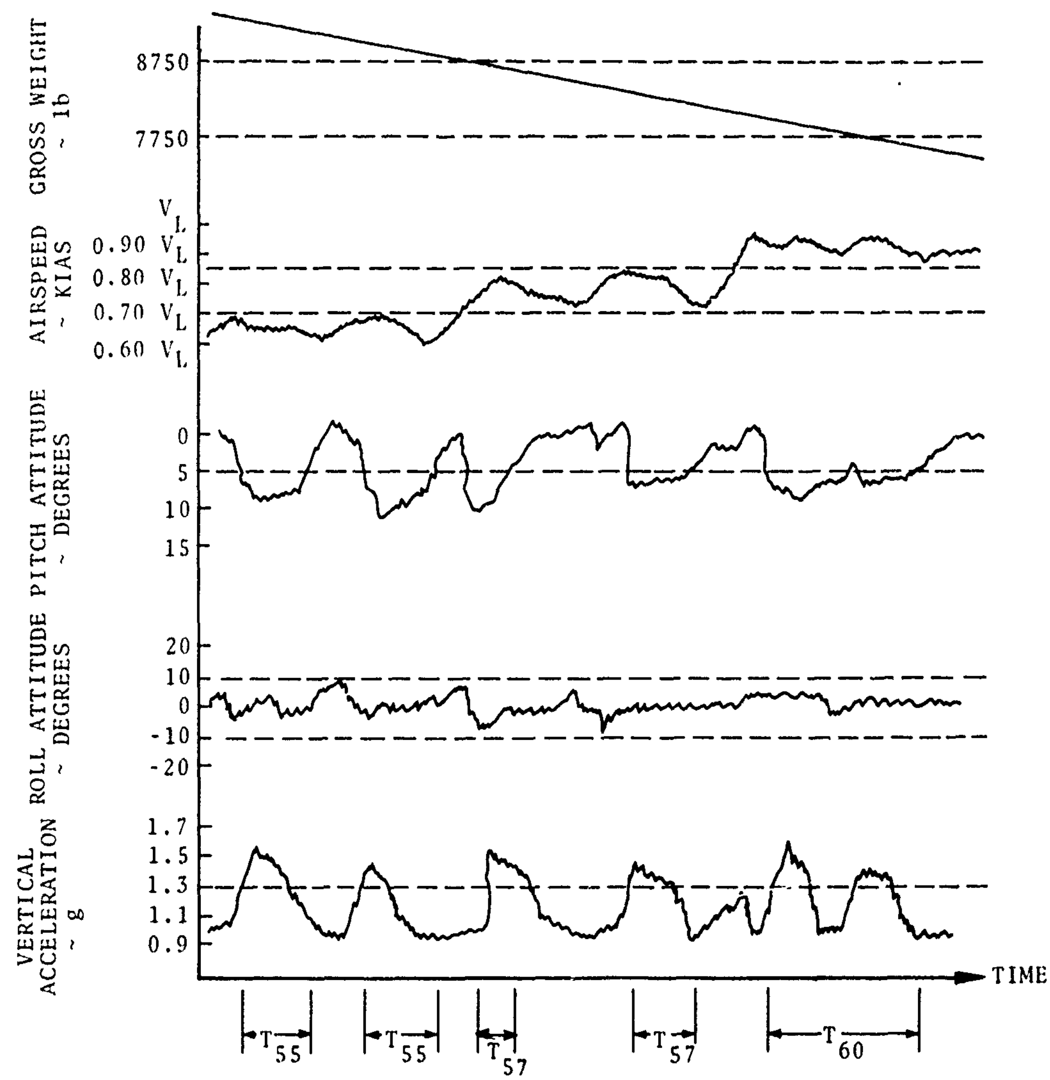
T_i = asymmetrical pullup occurrence timer for FCC #i, i = 41,52
$T_{\beta i}$ = time at which roll attitude first exceeds 10° threshold
T_{n_z} = time at which n_z exceeds 1.5 g threshold
ΔT_β = time between roll attitude threshold exceedances

The time between $T_{\beta 1}$ and T_{n_z} should be defined at less than 10 seconds. The timer (T_i) initiates at $T_{\beta 1}$. If ΔT_β is less than 10 seconds, T_1 should be allowed to continue timing until the roll attitude once again drops below threshold; otherwise, terminate T_i at the time the roll attitude first drops back across the 10° threshold. Recall that the roll attitude peak must fall between 10° and 35°; if it peaks above 35° it will be categorized as a different flight condition. The airspeed classification is based on percentage of limit velocity (V_L), which is a function of density altitude. The airspeed categorization, for a given pullup, is defined at $T_{\beta 1}$.

Figure A-10. Concluded

Represents: Symmetrical (Gunnery Run) Pullups

FCC Applicability			
For $A/S \leq 0.70V_L$	For $0.70V_L < A/S \leq 0.85V_L$	For $A/S > 0.85V_L$	$n_z \geq 1.3g$ $\beta \leq 10°$ $\theta > 5°$
FCC #53	FCC #56	FCC #59	GW < 7750 lb
FCC #54	FCC #57	FCC #60	7750 lb ≤ GW ≤ 8750 lb
FCC #55	FCC #58	FCC #61	GW > 8750 lb

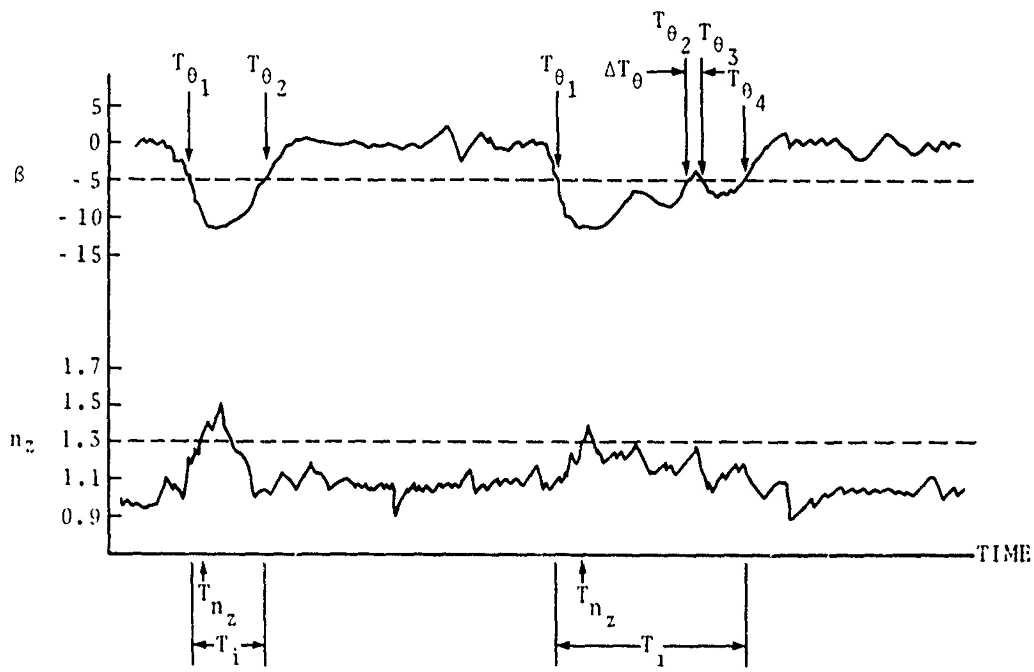


T_{53} = FCC #53 Timer
T_{54} = FCC #54 Timer
T_{55} = FCC #55 Timer
T_{56} = FCC #56 Timer
T_{57} = FCC #57 Timer
T_{58} = FCC #58 Timer
T_{59} = FCC #59 Timer
T_{60} = FCC #60 Timer
T_{61} = FCC #61 Timer

Figure A-11. Flight Condition Categories 53 through 61 (Symmetrical (Gunnery Run) Pullups).

Description

The following graphical characterization demonstrates how the time spent in symmetrical pullups should be defined.



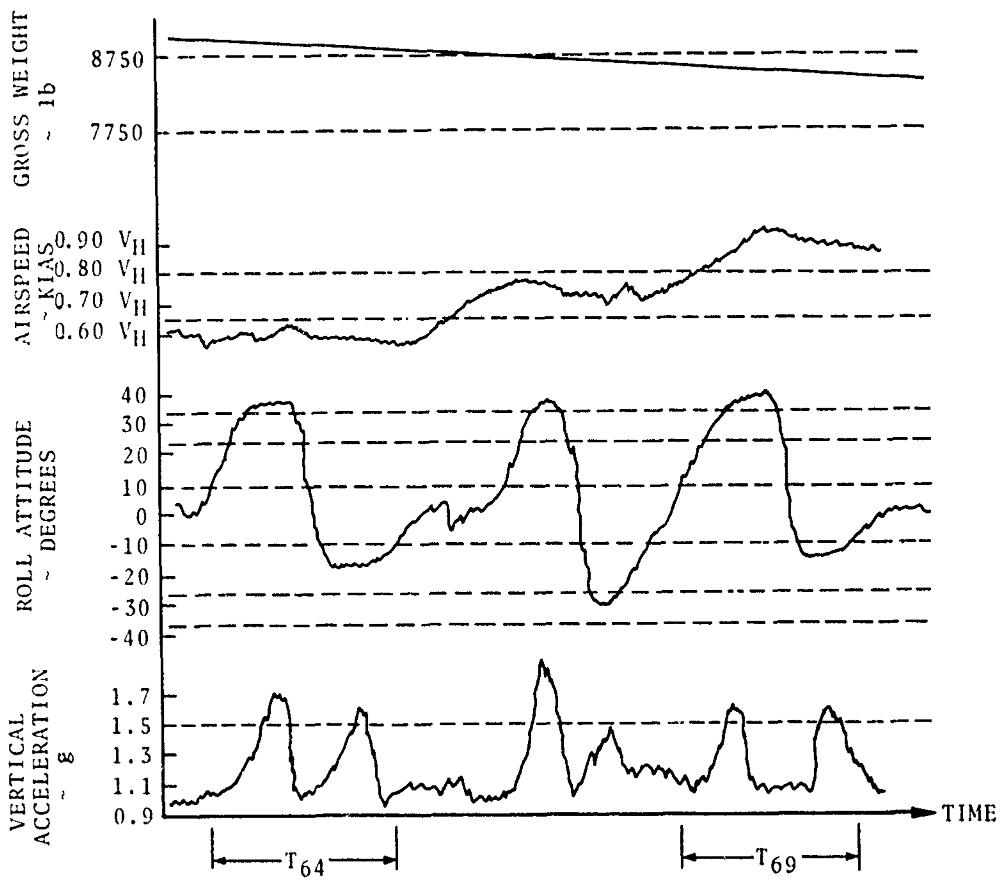
T_{θ_1} = time at which pitch attitude first exceeds -5°
$T_{\theta_{2,3,4}}$ = second, third, and fourth times the pitch attitude exceeds the -5° threshold
T_{n_z} = time at which n_z exceeds 1.3g threshold
ΔT_θ = time between pitch attitude -5° threshold exceedances

A gunnery run symmetrical pullup is confirmed when, and only when, T_{n_z} is sensed within 10 seconds after T_{θ_1} is sensed. The timer T_i initiates at T_{θ_1} and terminates at T_{θ_2}. The exception is when the pitch attitude briefly crosses inside the -5° threshold and then immediately returns outside threshold (ΔT_θ < 5 seconds). In this case the threshold crossing defined by ΔT_θ is ignored and T_i continues to time the maneuver until a normal termination is sensed. The airspeed classification is based on percentage of limit velocity (V_L), which is a function of density altitude. Airspeed is categorized at the time the vertical acceleration exceeds 1.3g.

Figure A-11. Concluded

Represents: Gunnery Turns

FCC Applicability			$n_z \geq 1.5g$
For	For	For	$\beta_{initial} \geq 35°$
$A/S \leq 0.65V_H$	$0.65V_H < A/S \leq 0.80V_H$	$A/S > 0.80V_H$	$\beta_{subsequent} < 25$
FCC #62	FCC #65	FCC #68	GW < 7750 lb
FCC #63	FCC #66	FCC #69	7750 lb < GW ≤ 8750 lb
FCC #64	FCC #67	FCC #70	GW > 8750 lb



T_{62} = FCC #62 Timer
T_{63} = FCC #63 Timer
T_{64} = FCC #64 Timer

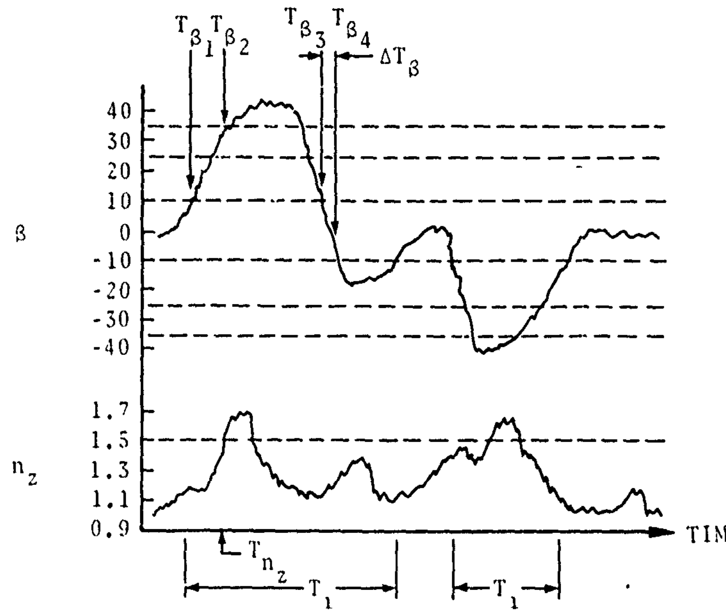
T_{65} = FCC #65 Timer
T_{66} = FCC #66 Timer
T_{67} = FCC #67 Timer

T_{68} = FCC #68 Timer
T_{69} = FCC #69 Timer
T_{70} = FCC #70 Timer

Figure A-12. Flight Condition Categories 62 through 70 (Gunnery Turns).

Description

The following graphical characterization demonstrates how the time spent in gunnery turns should be defined:



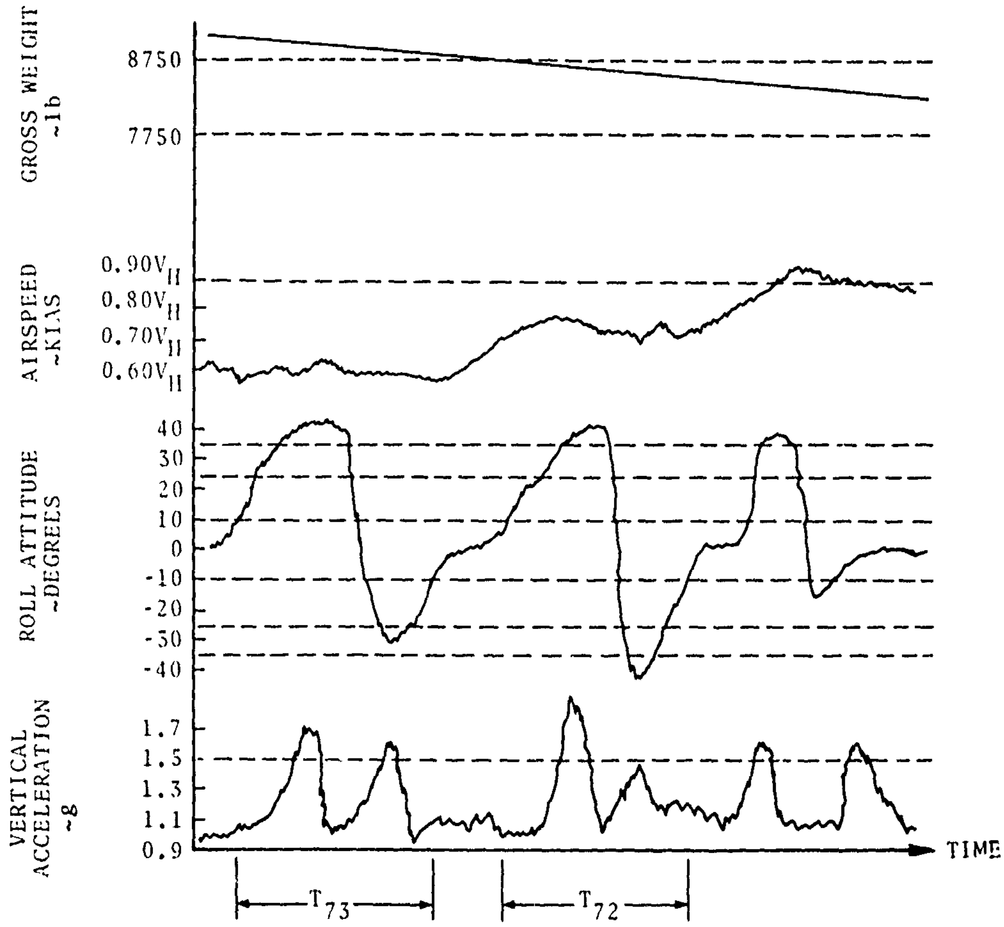
$T_{\beta 3,4}$ = second and third times the roll attitude crosses the 10° threshold level
T_i = gunnery turn occurrence timer for FCC #i, i = 22,24
$T_{\beta 1}$ = time at which roll attitude first exceeds 10° threshold
$T_{\beta 2}$ = time at which roll attitude first exceeds 35° threshold
T_{n_z} = time at which n_z exceeds 1.5g threshold
ΔT_β = time between roll attitude 10° threshold exceedances

The time between $T_{\beta 2}$ and T_{n_z} should be defined at less than 10 seconds. Upon confirmation that the roll attitude crosses the 35° threshold (the time between $T_{\beta 1}$ and $T_{\beta 2}$ should also be less than 10 seconds), the timer (T_i) initiates at $T_{\beta 1}$. If ΔT_β is less than 10 seconds, T_i should be allowed to continue timing until the roll attitude, once again, drops below the 10° threshold (at $T_{\beta 4}$), if and only if, the second roll attitude peak does not exceed 25°. Otherwise, terminate T_i at $T_{\beta 3}$. (The "subsequent peak" requirement is designed to differentiate gunnery turns from gunnery S-turns.) The airspeed classification is based on maximum attainable velocity at constant attitude (V_H), which is a function of density attitude. The airspeed categorization, for a given turn, is defined at $T_{\beta 1}$.

Figure A-12. Concluded

Represents: Gunnery S-Turn

FCC Applicability		$n_z \geq 1.5g$; $\beta_{initial} \geq 35°$; $\beta_{subsequent} \geq 25°$
For A/S < 0.90 V_H	For A/S ≥ 0.90 V_H	
FCC #71	FCC #74	GW < 7750 lb
FCC #72	FCC #75	7750 lb ≤ GW ≤ 8750 lb
FCC #73	FCC #76	GW > 8750 lb

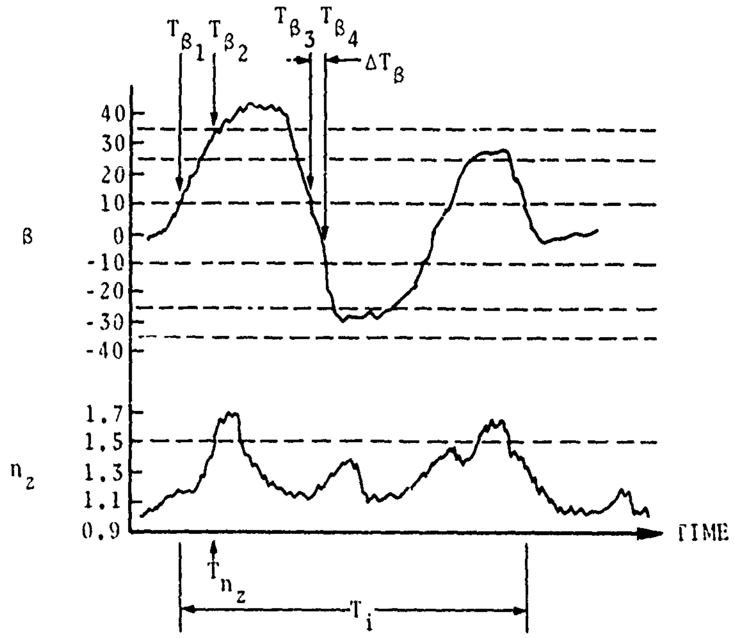


T_{71} = FCC #71 Timer
T_{72} = FCC #72 Timer
T_{73} = FCC #73 Timer
T_{74} = FCC #74 Timer
T_{75} = FCC #75 Timer
T_{76} = FCC #76 Timer

Figure A-13. Flight Condition Categories 71 through 76 (Gunnery S-Turns).

Description

The following graphical characterization demonstrates how the time spent in gunnery S-turns should be defined:



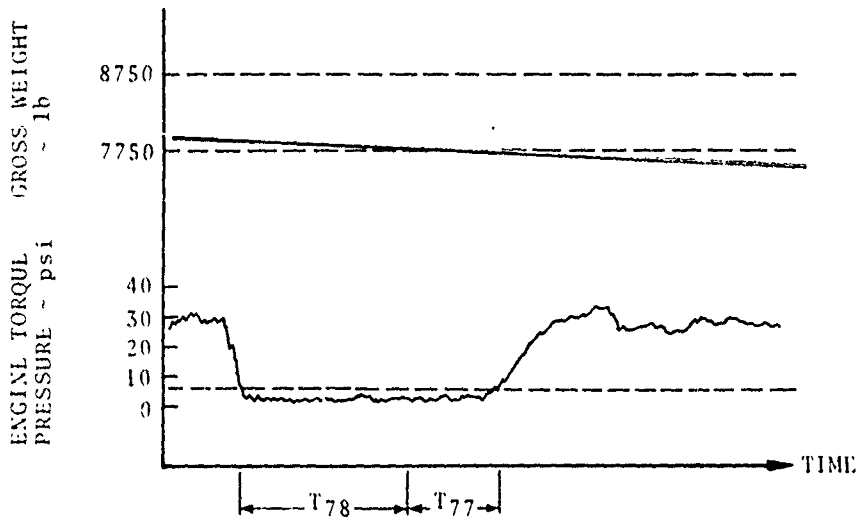
$T_{\beta 3,4}$ = second and third times the roll attitude crosses the 10° threshold level
T_i = gunnery turn occurrence timer for FCC #i, i = 22,24
$T_{\beta 1}$ = time at which roll attitude first exceeds 10° threshold
$T_{\beta 2}$ = time at which roll attitude first exceeds 35° threshold
T_{n_z} = time at which n_z exceeds 1.5g threshold
ΔT_β = time between roll attitude 10° threshold exceedances

The time between $T_{\beta 2}$ and T_{n_z} should be defined at less than 10 seconds. Upon confirmation that the roll attitude crosses the 35° threshold (the time between $T_{\beta 1}$ and $T_{\beta 2}$ should also be less than 10 seconds), the timer (T_i) initiates at $T_{\beta 1}$. If ΔT_β is less than 10 seconds, T_i should be allowed to continue timing until the roll attitude, once again, drops below the 10° threshold (at $T_{\beta 4}$), if and only if, the second (and any subsequent) roll attitude peaks exceed 25°. By definition, the gunnery S-turn is characterized by at least two excessive roll attitude peaks occurring in rapid succession. Therefore, the foregoing criteria concerning "subsequent peaks" was designed to differentiate the gunnery S-turn from normal gunnery turns. The airspeed classification is based on maximum attainable velocity at constant attitude (V_H), which is a function of density attitude. The airspeed categorization, for a given turn, is defined at $T_{\beta 1}$.

Figure A-13. Concluded

Represents: Clock Time in Autorotation

FCC Applicability	ET $\leq$ 5 psi
FCC #77	GW $\leq$ 7750 lb
FCC #78	7750 lb < GW $\leq$ 8750 lb
FCC #79	GW > 8750 lb



T_{77} = FCC #77 Timer
T_{78} = FCC #78 Timer
T_{79} = FCC #79 Timer

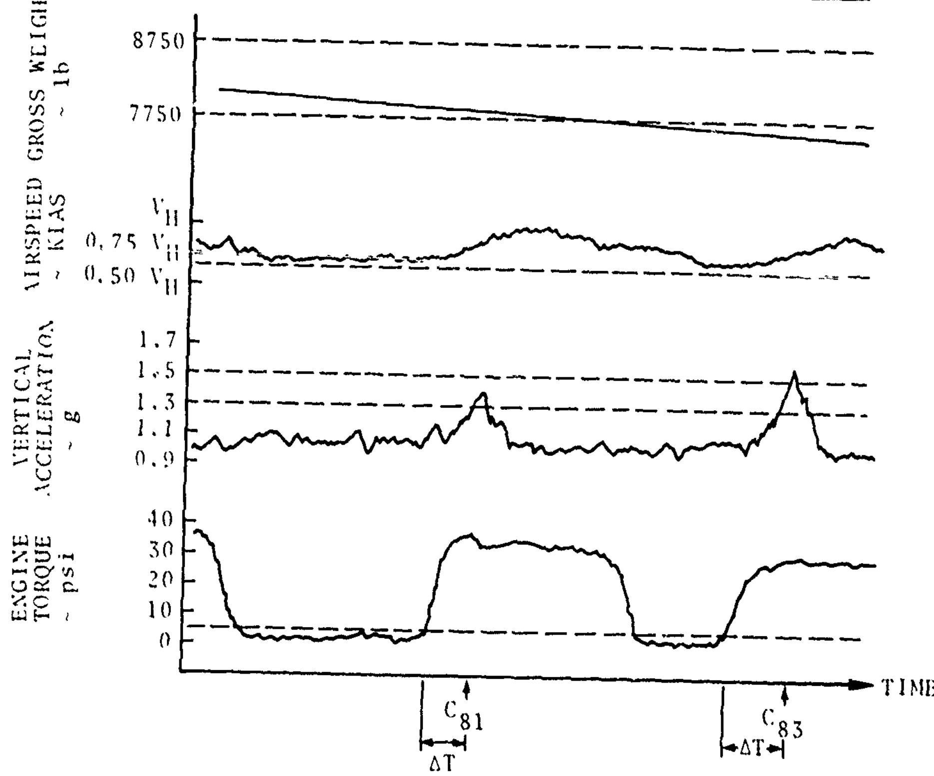
Description

Monitor the total flight spent in the autorotation mode of operation. Small perturbations in engine torque pressure (such as the torque pressure jumping above the 5 psi threshold for very short periods of time) of less than 2-second duration are ignored.

Figure A-14. Flight Condition Categories 77, 78, and 79 (Time in Autorotation).

Represents: Autorotation to Power Transition

FCC Applicability		
For $1.3g \le n_z \le 1.5g$	For $n_z > 1.5g$	A/S > 0.65 V_H ET crosses 5 psi (+)
FCC #80	FCC #83	GW < 7750 lb
FCC #81	FCC #84	7750 lb ≤ GW ≤ 8750 lb
FCC #82	FCC #85	GW > 8750 lb



T_{80} = FCC #80 Counter
T_{81} = FCC #81 Counter
T_{82} = FCC #82 Counter

T_{83} = FCC #83 Counter
T_{84} = FCC #84 Counter
T_{85} = FCC #85 Counter

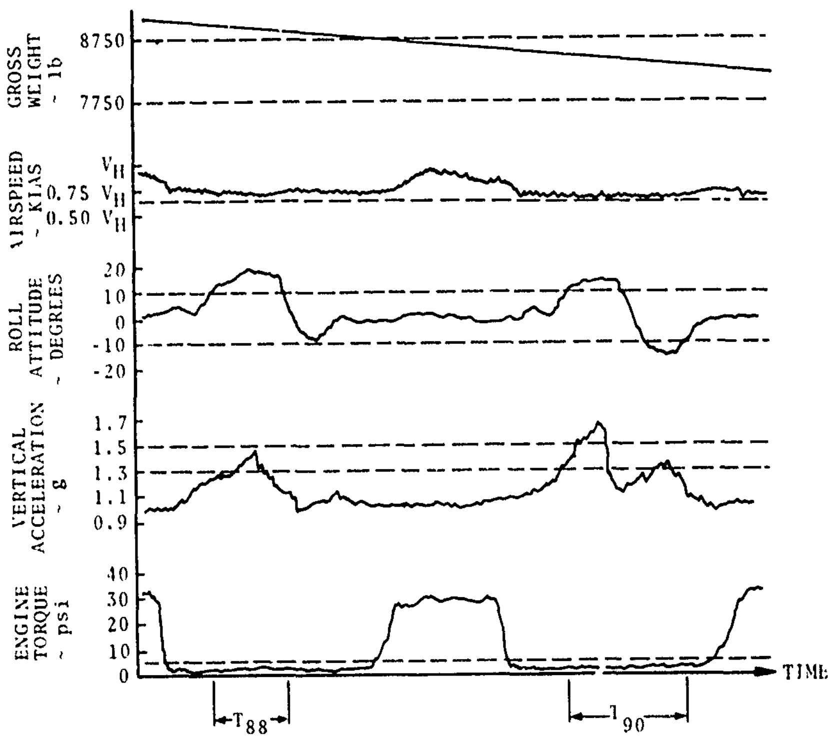
Description

Whenever the engine torque pressure crosses the 5 psi threshold in a positive direction and is followed (ΔT less than 5 seconds) by a vertical acceleration satisfying the threshold definition, the event should be recorded. The airspeed classification is based on a maximum attainable velocity at constant altitude (V_H), which is a function of density altitude. The airspeed categorization is defined at the time the vertical acceleration exceeds threshold.

Figure A-15. Flight Condition Categories 80 through 85 (Autorotation-to-Power Transition).

Represents: High-Speed Autorotation Turns

FCC Applicability		A/S > 0.65 V_H
For $1.3g \leq n_z \leq 1.5g$	For $n_z > 1.5g$	ET < 5 psi β > 10°
FCC #86	FCC #89	GW < 7750 lb
FCC #87	FCC #90	7750 lb < GW ≤ 8750 lb
FCC #88	FCC #91	GW > 8750 lb



T_{86} = FCC #86 Timer
T_{87} = FCC #87 Timer
T_{88} = FCC #88 Timer
T_{89} = FCC #89 Timer
T_{90} = FCC #90 Timer
T_{91} = FCC #91 Timer

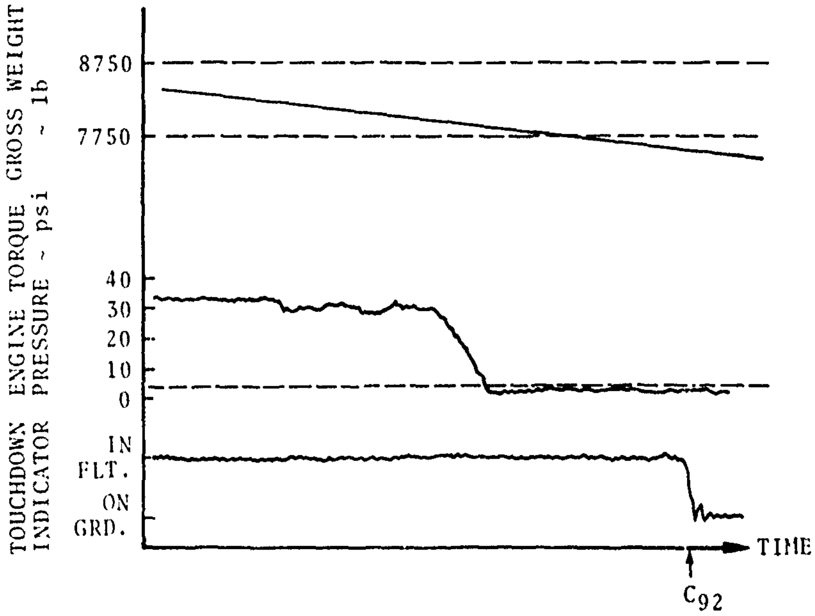
Description

Monitor the clock time accrued by the helicopter in autorotation while its roll attitude is greater than 10° only if it is accompanied by a vertical acceleration peak (within 5 seconds) in the prescribed threshold levels. The duration of the maneuver is defined the same as the Normal High-Speed Turn (FCC #23 through 28). The airspeed classification is based on maximum attainable velocity (V_H), which is a function of density altitude. The airspeed categorization for a given turn is defined at the time the roll attitude exceeds 10°.

Figure A-16. Flight Condition Categories 86 through 91 (High-Speed Autorotation Turns).

Represents: Autorotation Landing

	ET < 5 psi
FCC Applicability	TD ON/OFF
FCC #92	GW < 7750 lb
FCC #93	7750 lb ≤ GW ≤ 8750 lb
FCC #94	GW > 8750 lb



C_{92} = FCC #92 Counter
C_{93} = FCC #93 Counter
C_{94} = FCC #94 Counter

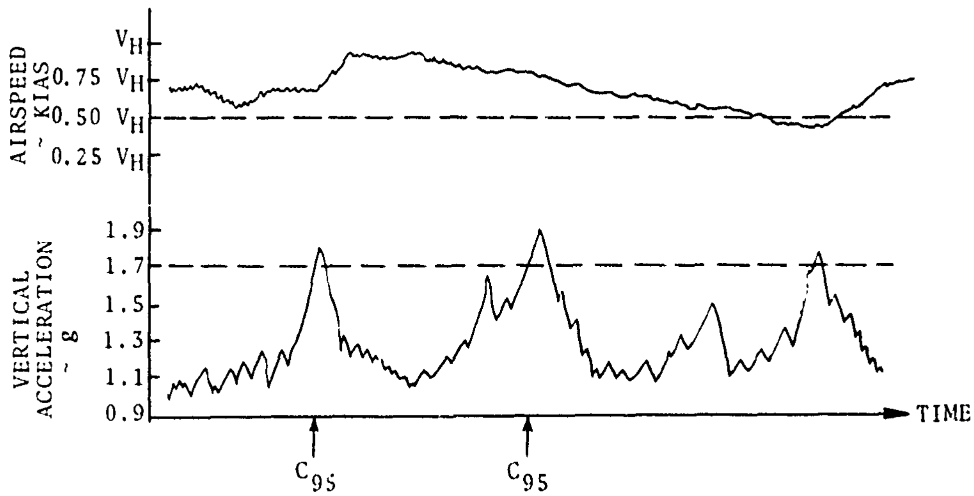
Description

The engine torque pressure must be below threshold immediately prior to (at least 10 seconds), and at the time of, touchdown. Once a touchdown has been recorded a rebounding helicopter should not register additional counts.

Figure A-17. Flight Condition Categories 92, 93, and 94 (Autorotation Landing).

$n_z \geq 1.7$ g
$A/S \geq .50\ V_H$

Represents: Misc. High-G Maneuvers



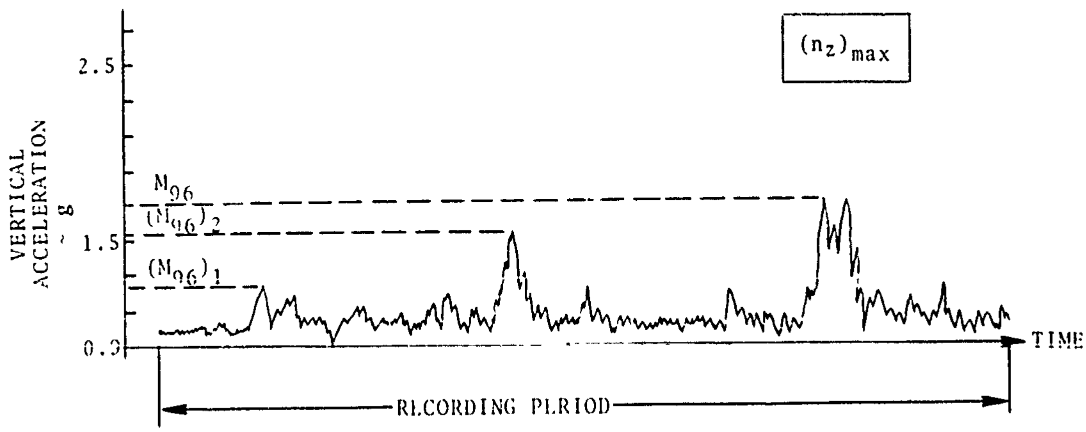
C_{95} = FCC #95 counter

Description

It is simply intended to count the number of times the helicopter experiences vertical accelerations in excess of 1.7 g while flying at significant airspeeds. This implies that the touchdown indicator must be registering in-flight operation.

Figure A-18. Flight Condition Category 95 (Miscellaneous High-G Maneuvers).

Represents: Maximum Vertical Acceleration



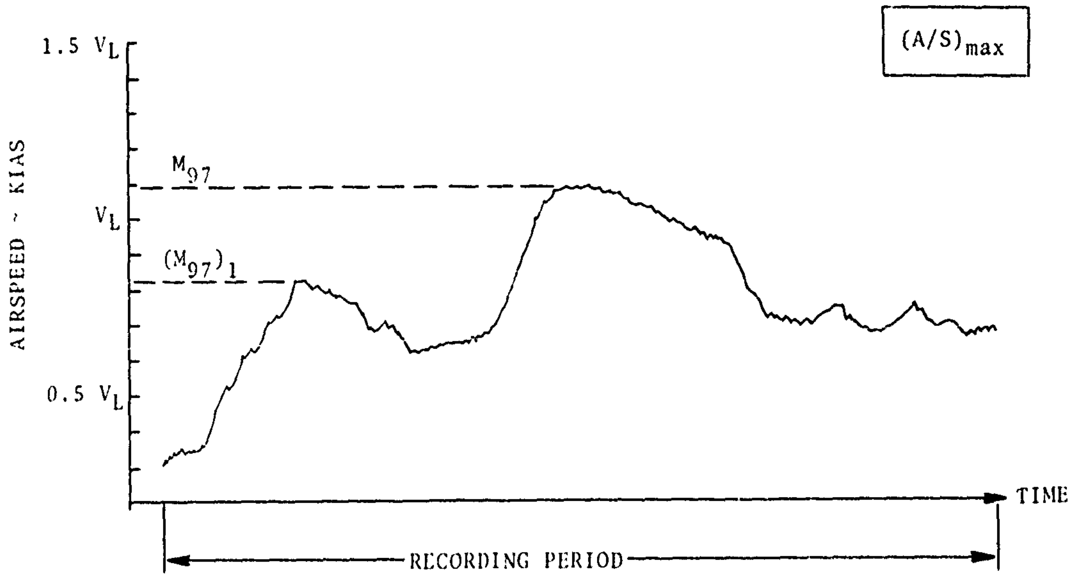
M_{96} = maximum n_z magnitude recorded during prescribed period
$(M_{96})_{1\&2}$ = intermediate maxima whose n_z values were subsequently surpassed during the recording period

Description

Record the magnitude of the largest vertical acceleration experienced during the recording period. The $(n_z)_{max}$ may occur in any flight condition category (which implies that the in-flight indicator must be registering in-flight operation).

Figure A-19. Flight Condition Category 96 (Maximum Vertical Acceleration).

Represents: Maximum Airspeed
Attained During All
Flight Conditions



M_{97} = maximum airspeed magnitude recorded during prescribed period

$(M_{97})_1$ = intermediate maxima whose airspeed values were subsequently surpassed during the recording period

Description

Record the magnitude of the highest airspeed experienced during the recording period expressed in terms of percent of V_L. The $(A/S)_{max}$ may occur in any flight condition category. (Recall that the value of V_L is a function of density altitude.)

Figure A-20. Flight Condition Category 97 (Maximum Airspeed (V_L)).

APPENDIX B

SIRS RECORDER SOFTWARE

```
PAGE  001    SIRSR

                        NAM     SIRSR
                        OPT     NOG
                *********************************************
                ****  STRUCTURAL INTEGRITY RECORDING SYSTEM ****
                ****            RECORDER PROGRAM            ****
                *********************************************

       2000     AD      EQU     $2000       A/D INPUT REGISTER
       2001     ADCR    EQU     $2001       A/D CONTROL REGISTER
       2002     MUX     EQU     $2002       MUX OUTPUT REGISTER
       2003     MUXCR   EQU     $2003       MUX CONTROL REGISTER
       1000     ACIACS  EQU     $1000       ACIA CONTROL/STATUS REGISTER
       1001     ACIAXR  EQU     $1001       ACIA TRANSMIT/RECEIVE REGISTE
       000F     MUXIO   EQU     $0F         PB3 - PB0 ARE OUTPUTS
       0034     ADCW    EQU     %00110100   A/D CONTROL WORD
       003C     ADSTRT  EQU     %00111100   A/D START WORD
       0004     MUXCW   EQU     %00000100   MUX CONTROL WORD
       0089     ACIACW  EQU     %10001001   ACIA CONTROL WORD
       0310     GWTIME  EQU     $0310       TIME TO DECREASE GROSS WT
       00AF     GW7750  EQU     175         7750 LB THRESHOLD
       00E1     GW8750  EQU     225         8750 LB THRESHOLD
       000D     PT05    EQU     13          13/256 = 0.05
       001A     PT10    EQU     26          26/256 = 0.10
       0026     PT15    EQU     38          38/256 = 0.15
       00F3     PT95    EQU     243         243/256 = 0.95
       0016     DEG5    EQU     22          PITCH = 5 DEG THRESHOLD
       002C     DEG10   EQU     44          ROLL = 10 DEG THRESHOLD
       0040     DEG15   EQU     64          PITCH = 15 DEG THRESHOLD
       006E     DEG25   EQU     110         ROLL = 25 DEG THRESHOLD
       0093     DEG35   EQU     147         ROLL = 35 DEG THRESHOLD
       000A     PSI5    EQU     10          LOW TORQUE THRESHOLD
       00DC     PSI44   EQU     220         HIGH TORQUE THRESHOLD
       0014     GWGND   EQU     20          GROUND THRESHOLD
       00C8     RPM200  EQU     200         RPM = 200 THRESHOLD
       0064     RPM100  EQU     100         RPM = 100 THRESHOLD
       01F7     GROSWT  EQU     $01F7       GROSS WEIGHT LOCATION
       01F8     NZPK    EQU     $01F8       NZ PEAK LOCATION
       01F9     VLPK    EQU     $01F9       VL PEAK LOCATION
       01FA     NZINT   EQU     $01FA       NZ CORRECTION INTERCEPT
       01FB     NZSLP   EQU     $01FB       NZ CORRECTION SLOPE
       01FC     ALTINT  EQU     $01FC       ALTITUDE CORRECTION INTERCEPT
       01FD     ALTSLP  EQU     $01FD       ALTITUDE CORRECTION SLOPE
       01FE     ASINT   EQU     $01FE       AIRSPEED CORRECTION INTERCEPT
       01FF     ASSLP   EQU     $01FF       AIRSPEED CORRECTIO SLOPE
       00FF     STACK   EQU     $00FF       START STACK HERE
```

```
            ***********************
            **  PARAMETER CODES  **
            ***********************
            * THE FOLLOWING CODES ARE SETUP BY THE DATA
            *  ACQUISITION PORTION OF THE SIRSP PROGRAM. THEY
            *  ARE USED BY THE EVENT RECOGNITION ROUTINES
            *  IN THE DEFINITION OF SIGNIFICANT FLIGHT
            *  CONDITIONS.
            *  PARAMETER   CODE    INTERPRETATION
            *    CVL        -1       A/S<=.7VL
            *                0       .7VL<A/S<=.85VL
            *                1       .85VL<A/S<=.95VL
            *                2       .95VL<A/S
            *
            *    CVH        -2        A/S<.5VH
            *               -1       .5VH<=A/S<.65VH
            *                0       .65VH<=A/S<.8VH
            *                1       .8VH<=A/S<.9VH
            *                2       .9VH<=A/S<.95VH
            *                3       .95VH<=A/S
            *
            *    CROL       -1       ROLL<10 DEG
            *                0       10<=ROLL<25 DEG
            *                1       25<=ROLL<35 DEG
            *                2 S     35<=ROLL
            *
            *    CQ          0 S     TORQUE<=5 PSI
            *                1       5<TORQUE<=44 PSI
            *                2       44<TORQUE
            *
            *    CRD        -1 S     NOT VALID
            *                0       RD<1650 FPM
            *                1       RD>=1650 FPM
            *
            *    CRPM       -1       RPM<100
            *                0       100<=RPM<=200
            *                1 S     RPM>200
            *
            *    CT          0 S     FLIGHT
            *                1       GROUND
            *
            *    CNZ        -1       NZ<=1.3 G
            *                0       1.3<NZ<=1.5 G
            *                1       1.5<NZ<=1.7 G
            *                2 S     NZ>1.7 G
            *
            *    CGW         0 S     GW<7750 LB
            *                1       7750<=GW<=8750 LB
            *                2       GW>8750 LB
            *
            *    CPIT       -1       0<PITCH<=5 DEG
            *                0       5<PITCH<=15 DEG
            *                1 S     PITCH>15 DEG
0
```

13
F

```
0000                 ORG     $0
                     *
                     *  PARAMETER VALUE CODES
0000 0001  CVL      RMB     1          0
0001 0001  CVH      RMB     1          1
0002 0001  CROL     RMB     1          2
0003 0001  CQ       RMB     1          3
0004 0001  CRD      RMB     1          4
0005 0001  CRPM     RMB     1          5
0006 0001  CT       RMB     1          6
0007 0001  CNZ      RMB     1          7
0008 0001  CGW      RMB     1          8
0009 0001  CPIT     RMB     1          9
                     *  MISC FLAGS AND SWITCHES
000A 0001  IFLAG    RMB     1          10
000B 0001  ARM2     RMB     1          11
000C 0001  OTIM     RMB     1          12
000D 0001  AIR      RMB     1          13
000E 0001  T77      RMB     1          14
000F 0002  T23A     RMB     2          15
0011 0001  MODE     RMB     1          17
0012 0001  TOHI     RMB     1          18
0013 0001  TOLO     RMB     1          19
0014 0001  M        RMB     1          20
0015 0001  NZE      RMB     1          21
0016 0001  NZHI     RMB     1          22
0017 0001  NZLO     RMB     1          23
0018 0001  HIROL    RMB     1          24
0019 0001  SVH      RMB     1          25
001A 0001  SVL      RMB     1          26
001B 0001  IGW      RMB     1          27
001C 0002  T86      RMB     2          28
001E 0001  RMOD     RMB     1          30
001F 0001  ASF      RMB     1          31
0020 0001  PUFLAG   RMB     1          32
0021 0001  T80      RMB     1          33
0022 0001  NZF      RMB     1          34
0023 0001  ARM31    RMB     1          35
0024 0001  LOAS     RMB     1          36
0025 0002  ASV      RMB     2          37
0027 0002  NDX      RMB     2          39
0029 0002  INDX     RMB     2          41
002B 0001  GTS      RMB     1          43
002C 0003  BAA      RMB     3          44
002F 0001  PUFCTM   RMB     1          47
0030 0001  NOPUFG   RMB     1          48
0031 0001  PU10     RMB     1          49
0032 0001  GSV53    RMB     1          50
0033 0001  VSV53    RMB     1          51
0034 0002  T23      RMB     2          52
0036 0001  YSPUFG   RMB     1          54
0037 0004           RMB     4          (55-58-SPARE)
003B 0001  AIRTIM   RMB     1          59
003C 0003  CONE     RMB     3          60
```

13
B

```
00155 003F 0001    ONEVH  RMB    1      63
00156 0040 0001    DENOM  RMB    1      64
00157 0041 0001    ZERO1  RMB    1      65
00158 0042 0001    ANS    RMB    1      66
00159 0043 0001    NUM    RMB    1      67
00160 0044 0001    SHFTCT RMB    1      68
00161 0045 0002    SAVADR RMB    2      69
00162 0047 0002    SAVCNV RMB    2      71
00163 0049 0001    RTUFLG RMB    1      73
00164 004A 0010    CNVTAB RMB    16     74
00165 005A 0001    KNOTS  RMB    1      90
00166 005B 0001    ALTFT  RMB    1      91
00167 005C 0001    GWTH   RMB    1      92
00168 005D 0001    GWTL   RMB    1      93
00169 005E 0001    GWCNT  RMB    1      94
00170 005F 0001    GW1ST  RMB    1      95
00171 0060 0001    GWH    RMB    1      96
00172 0061 0001    GWL    RMB    1      97
00173 0062 0044    DVTABL RMB    68     98
00174 00A6 0001    AVGDVH RMB    1      166
00175 00A7 0001    AVGDVL RMB    1      167
00176 00A8 0001    AVGDVC RMB    1      168
00177      003F    ONEVL  EQU    ONEVH
00178      0045    SAVSTK EQU    SAVADR

00

00181 0100 0100    CNTRS  RMB    256
00182 0200 0100    ACNTR  RMB    256
```

```
3000                ORG     $3000

3000 0F      ADPTAB FCB     15        ( 0)RPM
3001 01             FCB     1         ( 1)ROLL ATTITUDE
3002 02             FCB     2         ( 2)ROLL REFERENCE
3003 08             FCB     8         ( 3)PITCH
3004 09             FCB     9         ( 4)TORQUE
3005 0B             FCB     11        ( 5)TORQUE REFERENCE
3006 03             FCB     3         ( 6)VERTICAL ACCEL. (NZ)
3007 04             FCB     4         ( 7)ALTITUDE
3008 07             FCB     7         ( 8)AIRSPEED
3009 0A             FCB     10        ( 9)OUTSIDE AIR TEMP. (OAT)
300A 00             FCB     0         (10)GROSS WEIGHT
300B 05             FCB     5         (11)BATTERY VOLTAGE
300C 0E             FCB     14        (12)RECORDER S/N LO
300D 0C             FCB     12        (13)RECORDER S/N HIGH
300E 06             FCB     6         (14)SPARE 1
300F 0D             FCB     13        (15)SPARE 2

3010 8E 00FF RESTAR LDS     #STACK    SET UP STACK
3013 86 0F          LDA A   #MUXIO    PB0 - PB3 OUTPUTS
3015 B7 2002        STA A   MUX       FOR MUX ADDRESS
3018 86 34          LDA A   #ADCW     CA2 IS OUTPUT
301A B7 2001        STA A   ADCR
301D 86 04          LDA A   #MUXCW
301F B7 2003        STA A   MUXCR
3022 86 89          LDA A   #ACIACW
3024 B7 1000        STA A   ACIACS
3027 CE 02FF        LDX     #$02FF

302A 4F             CLR A             ********************
302B A7 00   CLRMOR STA A   0,X       *       CLEAR      *
302D 09             DEX               * SCRATCHPAD MEMORY *
302E 26 FB          BNE     CLRMOR    *******************

3030 0E             CLI               ENABLE INTERRUPT

3031 CE 0203 CLRFLG LDX     #$0203
3034 DF 00          STX     CVL       CVL+1 = CVH
3036 CE 0200        LDX     #$0200
3039 DF 02          STX     CROL      CROL+1 = CQ
303B CE 0001        LDX     #$0001
303E DF 04          STX     CRD       CRD+1 = CRPM
3040 7A 0004        DEC     CRD
3043 DF 08          STX     CGW       CGW+1 = CPIT
3045 08             INX
3046 DF 06          STX     CT        CT+1 = CNZ

3048 8D 02          BSR     ADCNVT
304A 20 43          BRA     CORNZ
```

```
                     ***********************
                     *MAKE A/D CONVERSIONS *
                     *STORE RESULTS IN     *
                     *CONVERSION TABLE     *
                     ***********************
                     *    SUBROUTINE       *
                     ***********************

304C 4F        ADCNVT CLR A                 ***********************
304D 86 0B            LDA A  #11            *GET # OF CONVERSIONS*
304F D6 49            LDA B  RTUFLG         *11 DURING RECORDING *
3051 26 02            BNE    SKP1           *16 DURING RETRIEVAL *
3053 86 10            LDA A  #16            ***********************

3055 CE 3000   SKP1   LDX    #ADRTAB        MUX ADDRESS TABLE
3058 DF 45            STX    SAVADR
305A CE 004A          LDX    #CNVTAB        TABLE FOR RESULTS
305D DF 47            STX    SAVCNV
305F DE 45     REPEAT LDX    SAVADR         GET MUX ADDRESS
3061 E6 00            LDA B  0,X
3063 F7 2002          STA B  MUX            SEND MUX ADDRESS
3066 5F               CLR B
3067 09        DELAY  DEX                   ***************
3068 08               INX                   *DELAY FOR MUX*
3069 5A               DEC B                 *TO SETTLE    *
306A 26 FB            BNE    DELAY          ***************
306C F6 2000          LDA B  AD             CLEAR A/D DONE
306F C6 3C            LDA B  #ADSTRT        *********************
3071 F7 2001          STA B  ADCR           * START CONVERSION  *
3074 C6 34            LDA B  #ADCW          *READY FOR NEXT TIME*
3076 F7 2001          STA B  ADCR           *********************
3079 7C 0045          INC    SAVADR         PREPARE FOR NEXT ADDRESS
307C DE 47            LDX    SAVCNV
307E F6 2001   ENDCVT LDA B  ADCR
3081 2A FB            BPL    ENDCVT         WAIT FOR END OF CONVERSION
3083 F6 2000          LDA B  AD             GET CONVERSION
3086 E7 00            STA B  0,X            STORE IN CONVERSION TABLE
3088 7C 0047          INC    SAVCNV         PREPARE FOR NEXT CONVERSION
308B 4A               DEC A                 CHECK FOR LAST CONVERSION
308C 26 D1            BNE    REPEAT
308E 39               RTS
```

```
00277                      ***********************
00278                      *     CORRECT NZ      *
00279                      ***********************

00281 308F B6 01FA CORNZ  LDA A  NZINT     INTERCEPT CORRECTION
00282 3092 D6 50          LDA B  CNVTAB+6  NZ CONVERSION
00283 3094 97 43          STA A  NUM       STORE INTERCEPT FOR XCER
00284 3096 B6 01FB        LDA A  NZSLP     SLOPE CORRECTION
00285 3099 8D 48          BSR    XCER      PUTS CORRECTED NZ IN ACC A
00286 309B 97 50          STA A  CNVTAB+6  RETURN CORRECTED NZ

00288                      ************************
00289                      *     SET CNZ FLAG     *
00290                      ************************

00293 309D CE 30AA        LDX    #NZTABL
00294 30A0 A1 00   LOOP   CMP A  0,X       (NZ 1.7, 1.5, 1.3, OR 0)
00295 30A2 24 0A          BCC    NZPEAK    BR IF NZ > TABLE VALUE
00296 30A4 7A 0007        DEC    CNZ
00297 30A7 08             INX
00298 30A8 20 F6          BRA    LOOP

00300 30AA 5A      NZTABL FCB    90,64,38,0  1.7,1.5,1.3 G THRESHOLDS

00302                      ****************************
00303                      *     CHECK NZ PEAK FCC    *
00304                      ****************************

00306 30AE F6 01F8 NZPEAK LDA B  NZPK      GET PEAK NZ VALUE LDX #NZPK
00307 30B1 11             CBA              (PRESENT NZ - FCC PEAK)
00308 30B2 25 03          BCS    ASCOR     BR IF PEAK > PRESENT VALUE
00309 30B4 B7 01F8        STA A  NZPK      STORE IF LARGER
```

```
                       ********************************
                       *CORRECT DIFFERENTIAL PRESSURE*
                       ********************************

30B7 B6 01FE ASCOR  LDA A  ASINT    INTERCEPT CORRECTION
30BA D6 52          LDA B  CNVTAB+8 DIFFERENTIAL PRESSURE
30BC 97 43          STA A  NUM      STORE INTERCEPT FOR XCER
30BE B6 01FF        LDA A  ASSLP    SLOPE CORRECTION
30C1 8D 20          BSR    XCER     PUTS CORRECTED PDIFF IN ACC A
30C3 97 52          STA A  CNVTAB+8 RETURN CORRECTED PDIFF

                       **************************
                       *    CONVERT TO KNOTS    *
                       *STORE RESULTS AT "KNOTS"*
                       **************************

30C5 CE 33B3        LDX    #ASTABL
30C8 8D 2F          BSR    LINEAR
30CA D7 5A          STA B  KNOTS


                       ***************************
                       *CORRECT ABSOLUTE PRESSURE*
                       ***************************

30CC B6 01FC        LDA A  ALTINT   INTERCEPT CORRECTION
30CF D6 51          LDA B  CNVTAB+7 ABSOLUTE PRESSURE
30D1 97 43          STA A  NUM      STORE INTERCEPT FOR XCER
30D3 B6 01FD        LDA A  ALTSLP   SLOPE CORRECTION
30D6 8D 0B          BSR    XCER     PUTS CORRECTED PABS IN ACC A
30D8 97 51          STA A  CNVTAB+7 RETURN CORRECTED PABS

                       *********************
                       *CONVERT TO FEET    *
                       *12 COUNTS = 1000 FT*
                       *********************

30DA CE 3398        LDX    #ALTABL
30DD 8D 1A          BSR    LINEAR
30DF D7 5B          STA B  ALTFT
30E1 20 28          BRA    DALT1
```

```
                    ************************************
                    *TRANSDUCER CORRECTION SUBROUTINE *
                    *SLOPE & INTERCEPT ARE IN ACC'S   *
                    *INTERCEPT IS AT "NUM"            *
                    *RESULT RETURNED IN ACC A         *
                    ************************************

30E3 8D 59   XCER   BSR    MPY7
30E5 4D             TST A          TEST FOR OVERFLOW
30E6 26 0E          BNE    ALLONE  BR IF OVERFLOW
30E8 96 43          LDA A  NUM     GET INTERCEPT
30EA 4D             TST A          + OR - INTERCEPT?
30EB 2A 06          BPL    PLUSA   BR IF INTERCEPT POSITIVE
30ED 1B             ABA            -INTERCEPT
30EE 25 08          BCS    END     BR IF RESULT IS NOT < 0
30F0 4F      ZERO   CLR A          RESULT < ZERO
30F1 20 05          BRA    END
30F3 1B      PLUSA  ABA            + INTERCEPT
30F4 24 02          BCC    END     BR IF RESULT IS   256
30F6 86 FF   ALLONE LDA A  #$FF    RESULT > 255
30F8 39      END    RTS

                    *************************
                    *LINEARIZE SUBROUTINE   *
                    *INX PRESET AT TABLE    *
                    *INPUT IN ACC A         *
                    *RESULT RETURNED IN ACC B*
                    *************************

30F9 A1 00   LINEAR CMP A  0,X
30FB 24 05          BCC    DELTA
30FD 08             INX
30FE 08             INX
30FF 08             INX
3100 20 F7          BRA    LINEAR
3102 A0 00   DELTA  SUB A  0,X
3104 E6 02          LDA B  2,X     SLOPE
3106 8D 3D          BSR    MPY5
3108 EB 01          ADD B  1,X
310A 39             RTS
```

```
                        **************************
                        *DENSITY ALTITUDE RTN    *
                        *ALTFT IS IN ACC B       *
                        *RESULT STORED ON STACK  *
                        **************************

310B 86 54     DALT1  LDA A  #84
310D 8D 28            BSR    MPY8
310F 86 6E     NXT1   LDA A  #110
3111 1B               ABA
3112 D6 53            LDA B  CNVTA3+9 GET TEMPERATURE
3114 10               SBA
3115 24 0D            BCC    PLSCOR
3117 40               NEG A
3118 C6 BF            LDA B  #191
311A 8D 1B            BSR    MPY8
311C 96 5B     NXT2   LDA A  ALTFT
311E 11               CBA
311F 25 0E            BCS    NEGALT
3121 10               SBA
3122 20 10            BRA    GO
3124 C6 AE     PLSCOR LDA B  #174
3126 8D 0F            BSR    MPY8
3128 96 5B     NXT3   LDA A  ALTFT
312A 1B               ABA
312B 25 05            BCS    HIALT     BR IF DALT > 255
312D 20 05            BRA    GO
312F 4F        NEGALT CLR A
3130 20 02            BRA    GO
3132 86 FF     HIALT  LDA A  #$FF
3134 36        GO     PSH A
3135 20 41            BRA    VL
```

```
                   ***************************************
                   *    MULTIPLY SUBROUTINE ACC A X ACC B    *
                   *MOST SIG. HALF OF RESULT RETURNED IN ACC A*
                   *LEAST SIG. HALF RETURNED IN ACC B        *
                   ***************************************

3137 36       MPY8  PSH A                *               *
3138 86 08          LDA A  #8            *  ZERO1 NOT 0  *
313A 97 41          STA A  ZERO1         *ROUNDOFF RESULT*
313C 20 0D          BRA    MPY           *               *
313E 36       MPY7  PSH A                *STORE NUMBER OF*
313F 86 07          LDA A  #7            *  FINAL SHIFTS *
3141 97 41          STA A  ZERO1         *               *
3143 20 06          BRA    MPY           *               *
3145 36       MPY5  PSH A                *   ZERO1 = 0   *
3146 86 05          LDA A  #5            *DO NOT ROUNDOFF*
3148 7F 0041        CLR    ZERO1         *               *
314B 97 44    MPY   STA A  SHFTCT
314D 86 08          LDA A  #8
314F 36             PSH A
3150 DF 29          STX    SNDX
3152 30             TSX
3153 4F             CLR A
3154 56             ROR B
3155 24 02    M3    BCC    M4
3157 AB 01          ADD A  1,X
3159 46       M4    ROR A
315A 56             ROR B
315B 6A 00          DEC    0,X
315D 26 F6          BNE    M3
315F 31             INS
3160 31             INS
3161 7D 0044        TST    SHFTCT    ANY FINAL SHIFTS
3164 27 0F          BEQ    RTN
3166 44       SHIFT LSR A
3167 56             ROR B
3168 7A 0044        DEC    SHFTCT
316B 26 F9          BNE    SHIFT     BRANCH FOR ANOTHER SHIFT
316D 24 06          BCC    RTN       BR IF FRACTIONAL PART OF
              *                      MULTIPLICATION < 0.5
316F 7D 0041        TST    ZERO1
3172 27 01          BEQ    RTN       BR IF NO ROUNDOFF
3174 5C             INC B

3175 DE 29    RTN   LDX    SNDX
3177 39             RTS
```

```
                      ************************
                      *   CALCULATE ONEVL    *
                      *DALT STARTS IN ACC A *
                      ************************

3178 80 24   VL       SUB A  #36
317A 25 09            BCS    LOW       BR IF DALT < 36 (3000 FT)
317C C6 AB            LDA B  #171
317E 8D B7            BSR    MPY8
3180 86 B4            LDA A  #180
3182 10               SBA
3183 20 02            BRA    ENDVL
3185 86 B4   LOW      LDA A  #180
3187 97 3F   ENDVL    STA A  ONEVL
                      **************
                      *SET CVL FLAG*
                      **************
3189 C6 F3            LDA B  #PT95
318B 8D AA            BSR    MPY8      .95VL RET'N IN ACC B
318D D1 5A            CMP B  KNOTS     .95VL - KNOTS
318F 25 14            BCS    VLPEAK    BR IF KNOTS > .95VL
3191 C6 26            LDA B  #PT15
3193 96 3F            LDA A  ONEVL
3195 8D A0            BSR    MPY8      .15VL RET'N IN ACC B
3197 96 3F            LDA A  ONEVL
3199 7A 0000 AGAIN1   DEC    CVL
319C 2B 07            BMI    VLPEAK    BR IF CVL = -1 (<.7VL)
319E 10               SBA
319F 91 5A            CMP A  KNOTS
31A1 25 02            BCS    VLPEAK    BR IF %VL < KNOTS
31A3 20 F4            BRA    AGAIN1

                      *******************
                      *CHECK VL PEAK FCC*
                      *******************

31A5 96 5A   VLPEAK   LDA A  KNOTS
31A7 D6 3F            LDA B  ONEVL
31A9 8D 48            BSR    DIVIDE    %VL IN ACC A
31AB F6 01F9          LDA B  VLPK
31AE 11               CBA              PRESENT VL - PEAK VL
31AF 25 03            BCS    VH        BR IF PEAK > PRESENT
31B1 B7 01F9          STA A  VLPK
```

```
                    *****************
                    *CALCULATE ONEVH*
                    *****************

31B4 32        VH      PUL A             GET DENSITY ALTITUDE
31B5 C6 2B             LDA B  #43
31B7 BD 3137           JSR    MPY8
31BA 86 90             LDA A  #144
31BC 10                SBA
31BD 97 3F             STA A  ONEVH
                    **************
                    *SET CVH FLAG*
                    **************

31BF 9F 45             STS    SAVSTK
31C1 86 26             LDA A  #PT15
31C3 D6 3F             LDA B  ONEVH
31C5 BD 3137           JSR    MPY8
31C8 37                PSH B             .15 VH ON STACK
31C9 86 1A             LDA A  #PT10
31CB D6 3F             LDA B  ONEVH
31CD BD 3137           JSR    MPY8
31D0 37                PSH B             .10 VH ON STACK
31D1 86 0D             LDA A  #PT05
31D3 D6 3F             LDA B  ONEVH
31D5 BD 3137           JSR    MPY8       .05 VH IN ACC B

31D8 96 3F             LDA A  ONEVH
31DA 8D 0E             BSR    CMPKN      1   - .05 = .95
31DC 8D 0C             BSR    CMPKN      .95 - .05 = .90
31DE 33                PUL B             .1
31DF 8D 09             BSR    CMPKN      .9  - .1  = .8
31E1 33                PUL B             .15
31E2 8D 06             BSR    CMPKN      .8  - .15 = .65
31E4 8D 04             BSR    CMPKN      .65 - .15 = .5

31E6 9E 45     PLENTR  LDS    SAVSTK
31E8 20 2B             BRA    ROLL

31EA 10        CMPKN   SBA
31EB 91 5A             CMP A  KNOTS
31ED 25 F7             BCS    PLENTR     BR IF KNOTS > %VH
31EF 7A 0001           DEC    CVH
31F2 39                RTS
```

```
                      ************************
                      * DIVIDE SUBROUTINE    *
                      ************************
                      * NUMERATOR IN ACC A   *
                      * DENOMINATOR IN ACC B *
                      *(NUM X 128)/DEN = ANS *
                      ************************

31F3 D7 40     DIVIDE STA B  DENOM
31F5 5F               CLR B
31F6 D7 41            STA B  ZERO1
31F8 D7 42            STA B  ANS      CLEAR ZERO & ANS
31FA 97 43            STA A  NUM
31FC 44               LSR A
31FD 56               ROR B
31FE 4D               TST A
31FF 26 04            BNE    SUBT     BR IF NUM WAS   1
3201 D1 40            CMP B  DENOM
3203 25 0F            BCS    SMALL    BR IF DENOM > (NUM X 128)
3205 D0 40     SUBT   SUB B  DENOM
3207 7C 0042          INC    ANS
320A 92 41            SBC A  ZERO1    SUBTRACT POSSIBLE BORROW
320C 26 F7            BNE    SUBT     BR IF NOT ZERO
320E D1 40            CMP B  DENOM
3210 24 F3            BCC    SUBT     BR IF ACC B   DENOM
3212 96 42            LDA A  ANS
3214 39        SMALL  RTS
```

```
                    ***********************
                    *     CORRECT ROLL    *
                    ***********************

3215 D6 40    ROLL    LDA B  CNVTAB+2 SYNCHRO REFERENCE
3217 96 4B            LDA A  CNVTAB+1 ROLL
3219 C1 91            CMP B  #145
321B 24 31            BCC    OUT1     BR IF REF > 145
321D C1 6F            CMP B  #111
321F 25 2D            BCS    OUT1     BR IF REF < 111
3221 8D D0            BSR    DIVIDE   CORRECT ROLL RETN IN ACC A
                    ***********************
                    *    SET CROL FLAG    *
                    ***********************
3223 81 93            CMP A  #DEG35
3225 24 11            BCC    PITCH    BR IF ROLL > 35
3227 7A 0002          DEC    CROL
322A 81 6E            CMP A  #DEG25
322C 24 0A            BCC    PITCH    BR IF ROLL > 25
322E 7A 0002          DEC    CROL
3231 81 20            CMP A  #DEG10
3233 24 03            BCC    PITCH    BR IF ROLL > 10
3235 7A 0002          DEC    CROL

                    *************************
                    *     CORRECT PITCH     *
                    *************************

3238 D6 40    PITCH   LDA B  CNVTAB+2 SYNCHRO REFERENCE
323A 96 4D            LDA A  CNVTAB+3 PITCH
323C 8D B5            BSR    DIVIDE   CORRECT PITCH RETN IN ACC A

                    ***********************
                    *    SET CPIT FLAG    *
                    ***********************

323E 81 40            CMP A  #DEG15
3240 24 12            BCC    CORRTQ   BR IF PITCH > 15
3242 7A 0009          DEC    CPIT
3245 81 16            CMP A  #DEG5
3247 24 0B            BCC    CORRTQ   BR IF PITCH > 5
3249 7A 0009          DEC    CPIT
324C 20 06            BRA    CORRTQ

324E 86 FF    OUT1    LDA A  #$FF
3250 97 09            STA A  CPIT
3252 97 02            STA A  CROL
```

```
                        **************************
                        *     COPRECT TORQUE     *
                        **************************

3254 D6 4F     CORRTQ LDA B  CNVTAB+5 TORQUE REFERENCE
3256 96 4E            LDA A  CNVTAB+4 TORQUE
3258 C1 91            CMP B  #145
325A 24 16            BCC    OUT2     BR IF REF > 145
325C C1 6F            CMP B  #111
325E 25 12            BCS    OUT2     BR IF PEF < 111
3260 8D 91            BSR    DIVIDE

                        ******************************
                        *        SET CO FLAG         *
                        ******************************

3262 91 0A            CMP A  PSI5
3264 25 0F            BCS    SETCT    BR IF TQ < 5 PSI
3266 7C 0003          INC    CQ
3269 91 DC            CMP A  PSI44
326B 25 08            BCS    SETCT    BR IF TQ < 44 PSI
326D 7C 0003          INC    CQ
3270 20 03            BRA    SETCT
3272 4F        OUT2   CLR A
3273 97 03            STA A  CQ
                        **************************
                        *     SET CT FLAG        *
                        **************************

3275 96 54     SETCT  LDA A  CNVTAB+10  GROSS WEIGHT TRANSDUCER
3277 81 14            CMP A  #GWGND   GROSS WEIGHT - GND THRESHOLD
3279 25 03            BCS    RPM      BR IF GW < GND THRESHOLD
327B 7C 0006          INC    CT

                        *************************
                        *     SET CRPM FLAG     *
                        *************************

327E 96 4A     RPM    LDA A  CNVTAB   RPM
3280 81 C8            CMP A  #RPM200  RPM - 200
3282 24 0A            BCC    AVGGW    BR IF RPM > 200
3284 7A 0005          DEC    CRPM
3287 81 64            CMP A  #RPM100  RPM - 100
3289 24 03            BCC    AVGGW    BR IF RPM > 100
328B 7A 0005          DEC    CRPM
```

```
                          ********************************
                          *     AVERAGE GROSS WEIGHT     *
                          ********************************

328E 5F        AVGGW  CLR B
328F 96 05            LDA A  CRPM
3291 2B 23            BMI    SKPCLR    BR IF RPM < 100

3293 CE 005E          LDX    #GWCNT    ************************
3296 E7 00     CLRGW  STA B  0,X       *         CLEAR        *
3298 08               INX              *GWCNT, GW1ST, GWH, GWL*
3299 8C 0062          CPX    #GWL+1    *      IF RPM > 100    *
329C 26 F8            BNE    CLRGW     ************************

329E 7C 005D          INC    GWTL      ***************************
32A1 26 03            BNE    SK2       *INCREMENT FUEL BURN TIMER*
32A3 7C 005C          INC    GWTH      *     (GWTH & GWTL)       *
32A6 DE 5C     SK2    LDX    GWTH      *                         *
32A8 8C 0310          CPX    #GWTIME   *   IF EQUAL TO (GWTIME   *
32AB 26 47            BNE    SETCGW    *  DECREMENT GROSS WEIGH) *
32AD 7A 01F7          DEC    GROSWT    *  (GROSWT) & CLEAR TIMER *
32B0 D7 5C            STA B  GWTH      *                         *
32B2 D7 5D            STA B  GWTL      *                         *
32B4 20 3E            BRA    SETCGW    ***************************

32B6 D7 5C     SKPCLR STA B  GWTH      *      CLEAR
32B8 D7 5D            STA B  GWTL      *FUEL BURN TIMER
32BA 96 54            LDA A  CNVTAB+10  GROSS WEIGHT
32BC 9B 61            ADD A  GWL       *********
32BE 97 61            STA A  GWL       *ADD FOR*
32C0 24 03            BCC    NXT4      *AVERAGE*
32C2 7C 0060          INC    GWH       *********
32C5 7C 005E   NXT4   INC    GWCNT     #INPUTS FOR AVERAGE
32C8 86 07            LDA A  #7
32CA 95 5E            BIT A  GWCNT
32CC 26 26            BNE    SETCGW    BR IF NOT 8 INPUTS

                      *************************
                      *     DIVIDE SUM OF     *
                      *     8 INPUTS BY 8     *
                      *************************

32CE 86 03            LDA A  #3
32D0 97 44            STA A  SHFTCT
32D2 96 60            LDA A  GWH
32D4 D6 61            LDA B  GWL
32D6 BD 3166          JSR    SHIFT
```

```
                          ********************************
                          *    CHECK PREVIOUS GROSS WEIGHT     *
                          *    UPDATE IF DIFFERENCE < 4        *
                          ********************************
32D9 17                        TBA               PUT AVG GROSS WEIGHT IN ACC A
32DA 97 61                     STA A  GWL
32DC D6 5F                     LDA B  GW1ST      GET PREVIOUS AVERAGE
32DE 27 0B                     BEQ    TO1ST      BR IF NO PREVIOUS AVERAGE
32E0 10                        SBA               GET DIFFERENCE OF AVERAGES
32E1 2A 01                     BPL    TST1       BR IF PLUS
32E3 43                        COM A             MAKE IT PLUS
32E4 80 04          TST1       SUB A  #4
32E6 24 03                     BCC    TO1ST      BR IF DIFFERENCE > 3
32E8 F7 01F7                   STA B  GROSWT     UPDATE GROSS WEIGHT
32EB 96 61          TO1ST      LDA A  GWL        *    BUMP PRESENT GW
32ED 97 5F                     STA A  GW1ST      *    TO "PREVIOUS" LOCATION
32EF 4F                        CLR A
32F0 97 61                     STA A  GWL
32F2 97 60                     STA A  GWH

                          ************************
                          *    SET CGW FLAG      *
                          ************************

32F4 B6 01F7        SETCGW     LDA A  GROSWT
32F7 81 AF                     CMP A  #GW7750
32F9 25 0A                     BCS    DECENT     BR IF GW < 7750
32FB 7C 0008                   INC    CGW
32FE 81 E1                     CMP A  #GW8750
3300 25 03                     BCS    DECENT     BR IF GW < 8750
3302 7C 0008                   INC    CGW
```

```
                      ****************************************
                      *     GET 1 SECOND ALTITUDE AVERAGE    *
                      *     LOAD DIVE TABLE FOR TIME 0       *
                      ****************************************

3305 96 02    DECENT LDA A  CROL
3307 2B 03           BMI    SK5       BR IF ROLL < 10
3309 7C 0066         INC    DVTABL+4
330C 96 03    SK5    LDA A  CQ
330E 26 03           BNE    SK6       BR IF TORQUE   5
3310 7C 0065         INC    DVTABL+3
3313 96 07    SK6    LDA A  CN2
3315 2B 03           BMI    SK7       BR IF N2 < 1.3
3317 7C 0067         INC    DVTABL+5
331A 7C 00A8  SK7    INC    AVGDVC    INC AVERAGE COUNTER
331D 96 A8           LDA A  AVGDVC
331F 81 09           CMP A  #9
3321 24 11           BCC    CHK10     BR IF 9 OR 10 AVERAGE INPUTS
3323 7F 00A8         CLR    AVGDVC
3326 D6 5B           LDA B  ALTFT     **********************
3328 DB A7           ADD B  AVGDVL    *                    *
332A D7 A7           STA B  AVGDVL    *   ADD FOR AVERAGE  *
332C 24 03           BCC    SKP4      *                    *
332E 7C 00A6         INC    AVGDVH    **********************
3331 7E 366F  SKP4   JMP    F1

3334 81 0A    CHK10  CMP A  #10
3336 25 5E           BCS    BRAF1     BR IF AVGDVC = 9
3338 86 03           LDA A  #3
333A 97 44           STA A  SHFTCT
333C 96 A6           LDA A  AVGDVH
333E D6 A7           LDA B  AVGDVL
3340 BD 3166         JSR    SHIFT     AVG RET'N IN ACC B
3343 D7 68           STA B  DVTABL+6  1 SEC ALTFT AVERAGE
3345 5F              CLR B
3346 D7 A7           STA B  AVGDVL
3348 D7 A6           STA B  AVGDVH
334A D6 01           LDA B  CVH
334C D7 63           STA B  DVTABL+1
334E D6 00           LDA B  CVL
3350 D7 64           STA B  DVTABL+2
3352 96 5A           LDA A  KNOTS
3354 D7 69           STA B  DVTABL+7
```

14
B

```
                        ********************************
                        *     SET DELTA FLAG IF        *
                        *     ALT(-6) - ALT(0) > 1     *
                        ********************************

3356 CE 0062                 LDX    #DVTABL
3359 6F 00                   CLR    0,X
335B E6 06                   LDA B  6,X       ALT(0)
335D CB 02                   ADD B  #2
335F A6 36                   LDA A  54,X      ALT(-6)
3361 10                      SBA              ALT(-6) - ALT(0) - 2
3362 25 02                   BCS    CHK9      BR IF ALT DID NOT DECREASE
                        *                     BY 2 CNTS IN LAST 6 SEC
3364 6C 00                   INC    0,X

                        **********************
                        *  SET CRD FLAG      *
                        **********************
3366 5C             CHK9     INC B            ALT(0) + 3
3367 A6 3C                   LDA A  60,X      ALT(-9)
3369 10                      SBA              ALT(-9) - ALT(0) - 3
336A 25 27                   BCS    SKP3      BR IF ALT DID NOT DECREASE
                        *                     BY 3 CNTS IN LAST 9 SEC


336C E6 43                   LDA B  67,X      A/S(-12)
336E CB 23                   ADD B  #35
3370 A6 37                   LDA A  55,X      A/S(-6)
3372 10                      SBA              A/S(-6) - A/S(-12) - 35 KNOTS
3373 25 1E                   BCS    SKP3      BR IF A/S DID NOT INCREASE BY
                        *                     35 KNOTS FROM (-12) TO (-6)


3375 5F                      CLR B
3376 86 F8          LP5      LDA A  #$F8      (-8)
3378 EB 00                   ADD B  0,X
337A 08             LP6      INX              *
337B 4C                      INC A            *INC X BY 8
337C 26 FC                   BNE    LP6       *
337E 8C 009A                 CPX    #DVTABL+56
3381 26 F3                   BNE    LP5       BR IF THERE MORE DELTAS
3383 C1 05                   CMP B  #5
3385 25 0C                   BCS    SKP3      BR IF SUM OF DELTAS < 5

3387 96 5B                   LDA A  ALTFT     ALTITUDE IN FEET
3389 81 78                   CMP A  #120      10,000 FEET
338B 24 06                   BCC    SKP3      BR IF ALTITUDE > 10,000 FT
338D 7C 0004                 INC    CPD
3390 BD 3600                 JSR    $3600     BUMP
3393 7C 0004        SKP3     INC    CRD
3396 20 39          BRAF1    BRA    DLOOPB

0
```

```
00861 3398 FC      ALTABL FCB    252,255, 0
00862 339B E5             FCB    229,      225, 44
00863 339E C7             FCB    199,      187, 40
00864 33A1 9C             FCB    156,      138, 36
00865 33A4 7C             FCB    124,      105, 34
00966 33A7 5A             FCB    90,       74, 30
00867 33AA 40             FCB    64,       51, 29
00868 33AD 25             FCB    37,       29, 26
00869 33B0 00             FCB    0,        0, 25
00870 33B3 FA      AITABL FCB    250,      202, 0
00871 33B6 B0             FCB    176,      171, 14
00872 33B9 70             FCB    112,      137, 17
00873 33BC 50             FCB    80,       116, 21
00874 33BF 32             FCB    50,       92, 26
00875 33C2 1E             FCB    30,       71, 32
00876 33C5 15             FCB    21,       59, 47
00877 33C8 0C             FCB    12,       45, 54
00878 33CB 05             FCB    5,        29, 77
00879 33CE 00             FCB    0,0,196
```

```
33D1 CE 2800 DLOOPB LDX   #MES2
33D4 BD 3554        JSR   PRT
33D7 BD 35C1        JSR   INP
33DA CE 2869        LDX   #MES7
33DD BD 3559        JSR   PRTR
33E0 CE 286E        LDX   #BUFFR
33E3 A6 00          LDA A 0,X
33E5 81 4E          CMP A #$4E       N?
33E7 27 12          BEQ   JF4X
33E9 81 4C          CMP A #$4C       L?
33EB 27 11          BEQ   JLO
33ED 84 4F          AND A #$4F
33EF 81 09          CMP A #$09
33F1 2F 0E          BLE   DLOOPJ
33F3 CE 281C        LDX   #MES3
33F6 BD 3559        JSR   PRTR
33F9 20 D6          BRA   DLOOPB
33FB 7E 3499 JF4X   JMP   JF4
33FE 7E 345A JLO    JMP   DLOOPS
3401 B7 340D DLOOPJ STA A DLOOPK+1
3404 B7 3456        STA A DLOOPQ+1
3407 CE 0000        LDX   #CVL
340A C6 30          LDA B #$30
340C A6 00   DLOOPK LDA A 0,X
340E 2A 04          BPL   DLOOPM
3410 43             COM A
3411 4C             INC A
3412 C6 2D          LDA B #$2D
3414 8A 30   DLOOPM ORA A #$30
3416 CE 286E        LDX   #BUFFR
3419 E7 02          STA B 2,X
341B A7 03          STA A 3,X
341D 5F             CLR B
341E E7 04          STA B 4,X
3420 C6 2A          LDA B #$2A
3422 E7 00          STA B 0,X
3424 C6 20          LDA B #$20
3426 E7 01          STA B 1,X
3428 BD 3554        JSR   PRT
342B CE 282F        LDX   #MES4
342E BD 3554        JSR   PRT
3431 BD 35C1        JSR   INP
3434 CE 2869        LDX   #MES7
3437 BD 3559        JSR   PRTR
343A CE 286E        LDX   #BUFFR
343D A6 00          LDA A 0,X
343F 81 0D          CMP A #$0D
3441 27 14          BEQ   DLOOPR
3443 81 2D          CMP A #$2D
3445 26 01          BNE   DLOOPN
3447 08             INX
3448 E6 00   DLOOPN LDA B 0,X
344A C4 0F          AND B #$0F
344C 81 2D          CMP A #$2D
```

```
3444E 26 02              BNE    DLOOPP
3450 53                  COM B
3451 5C                  INC B
3452 CE 0000 DLOOPP      LDX    #CVL
3455 E7 00   DLOOPQ      STA B  0,X
3457 7E 33D1 DLOOPR      JMP    DLOOPB
345A 7F 2855 DLOOPS      CLR    COUNT
345D 7A 2855             DEC    COUNT
3460 CE 0000 DLOOPT      LDX    #CVL
3463 7C 2855             INC    COUNT
3466 B6 2855             LDA A  COUNT
3469 81 09               CMP A  #9
346B 2E EA               BGT    DLOOPR
346D B7 3476             STA A  DLOOPU+1
3470 8A 30               ORA A  #$30
3472 B7 286E             STA A  BUFFR
3475 A6 00   DLOOPU      LDA A  0,X
3477 CE 286E             LDX    #BUFFR
347A C6 20               LDA B  #$20
347C E7 01               STA B  1,X
347E E7 02               STA B  2,X
3480 C6 30               LDA B  #$30
3482 E7 03               STA B  3,X
3484 4D                  TST A
3485 2A 06               BPL    DLOOPV
3487 C6 2D               LDA B  #$2D
3489 E7 03               STA B  3,X
348B 43                  COM A
348C 4C                  INC A
348D 8A 30   DLOOPV      ORA A  #$30
348F A7 04               STA A  4,X
3491 5F                  CLR B
3492 E7 05               STA B  5,X
3494 BD 3559             JSR    PRTR
3497 20 C7               BRA    DLOOPT
3499 CE 2835 JF4         LDX    #MES5
349C BD 3554             JSR    PRT
349F BD 35C1             JSR    INP
34A2 CE 2869             LDX    #MES7
34A5 BD 3559             JSR    PRTR
34A8 5F                  CLR B
34A9 F7 34C9             STA B  JF4D+1
34AC CE 286E             LDX    #BUFFR
34AF A6 01   JF4B        LDA A  1,X
34B1 81 0D               CMP A  #$0D
34B3 27 06               BEQ    JF4C
34B5 7C 34C9             INC    JF4D+1
34B8 08                  INX
34B9 20 F4               BRA    JF4B
34BB CE 286E JF4C        LDX    #BUFFR
34BE A6 00   JF4C1       LDA A  0,X
34C0 84 0F               AND A  #$0F
34C2 FF 2882             STX    SAVEX
34C5 CE 284F             LDX    #K1
```

```
34C8 EB 00    JF4D    ADD B  0,X
34CA 4A               DEC A
34CB 26 FB            BNE    JF4D
34CD B6 34C9          LDA A  JF4D+1
34D0 27 0A            BEQ    JF4F
34D2 4A               DEC A
34D3 B7 34C9          STA A  JF4D+1
34D6 FE 2882          LDX    SAVEX
34D9 08               INX
34DA 20 E2            BRA    JF4C1
34DC F7 2854  JF4F    STA B  LOOPCT
34DF 7E 360A          JMP    F4
              *
              *  AT END OF PASS
              *
34E2 7A 2854  FLOOPA  DEC    LOOPCT
34E5 27 03            BEQ    FLOOP1
34E7 7E 360A          JMP    F4
34EA CE 0100  FLOOP1  LDX    #$100
34ED 5F               CLR B
34EE 7F 2882          CLR    SAVEX
34F1 A6 00    FLOOPB  LDA A  0,X
34F3 08               INX
34F4 8C 0200          CPX    #$200
34F7 27 07            BEQ    FLOOP5
34F9 A1 FF            CMP A  255,X
34FB 26 13            BNE    FLOOPD
34FD 5C       FLOOP4  INC B
34FE 20 F1            BRA    FLOOPB
3500 CE 0100  FLOOP5  LDX    #$100
3503 86 FF            LDA A  #255
3505 E6 00    FLOOPC  LDA B  0,X
3507 08               INX
3508 E7 FF            STA B  255,X
350A 4A               DEC A
350B 26 F8            BNE    FLOOPC
350D 7E 33D1          JMP    DLOOPB
3510 7D 2882  FLOOPD  TST    SAVEX
3513 26 0B            BNE    FLOOPE
3515 FF 2882          STX    SAVEX
3518 CE 2856          LDX    #MES6
351B BD 3559          JSR    PRTR
351E 20 03            BRA    FLOOPF
3520 FF 2882  FLOOPE  STX    SAVEX
3523 37       FLOOPF  PSH B
3524 C6 20            LDA B  #$20
3526 BD 3575          JSR    PUTC
3529 33               PUL B
352A 37               PSH B
352B 36               PSH A
352C 17               TBA
352D BD 35D6          JSR    PRTDEC
3530 CE 2869          LDX    #MES7
3533 BD 3554          JSR    PRT
```

```
3536 FE 2882        LDX     SAVEX
3539 A6 FF          LDA A   255,X
353B BD 35D6        JSR     PRTDEC
353E CE 2969        LDX     #MES7
3541 BD 3554        JSR     PRT
3544 32             PUL A
3545 BD 35D6        JSR     PRTDEC
3548 CE 2969        LDX     #MES7
354B BD 3559        JSR     PRTR
354E FE 2882        LDX     SAVEX
3551 33             PUL B
3552 20 A9          BRA     FLOOP4
```

```
                            ***************************************************
                            ***************************************************
                            *  THE FOLLOWING ROUTINES HAVE BEEN INSERTED
                            *   FOR DEBUGGING PURPOSES ONLY AND WILL NOT
                            *   APPEAR IN THE FINAL VERSION OF THE SOFTWARE.
                            ********************************
                            *  PRINT SUBROUTINE
                            *
3554 36                     PRT     PSH A
3555 37                             PSH B
3556 4F                             CLR A
3557 20 04                          BRA     PRT3
3559 36                     PRTR    PSH A
355A 37                             PSH B
355B 86 AA                          LDA A   #$AA
355D C6 09                  PRT3    LDA B   #$09
355F F7 1000                        STA B   ACIACS
3562 E6 00                  PRT4    LDA B   0,X
3564 27 06                          BEQ     PRTEX
3566 BD 3575                        JSR     PUTC
3569 08                             INX
356A 20 F6                          BRA     PRT4
356C 4D                     PRTEX   TST A
356D 27 03                          BEQ     PRTX
356F BD 3575                        JSR     PUTC
3572 33                     PRTX    PUL B
3573 32                             PUL A
3574 39                             RTS
                            ***********************************
                            *  PUTC SUBROUTINE
                            *
3575 36                     PUTC    PSH A
3576 B6 1000                PUTC1   LDA A   ACIACS
3579 47                             ASR A
357A 47                             ASR A
357B 24 F9                          BCC     PUTC1
357D F7 1001                        STA B   ACIAXR
3580 C1 7F                          CMP B   #$7F
3582 27 11                          BEQ     PUTF
3584 BD 35AE                        JSR     DLAY
3587 5D                             TST B
3588 26 0B                          BNE     PUTF
358A C6 0D                          LDA B   #$0D
358C BD 3575                        JSR     PUTC
358F C6 0A                          LDA B   #$0A
3591 BD 3575                        JSR     PUTC
3594 5F                             CLR B
3595 32                     PUTF    PUL A
3596 39                             RTS
                            *************************************
                            *  GETC  SUBROUTINE
                            *
3597 36                     GETC    PSH A
3598 B6 1000                GETC1   LDA A   ACIACS
```

```
359B 47                 ASR A
359C 24 FA              BCC     GETC1
359E 48                 ASL A
359F 36                 PSH A
35A0 85 70              BIT A   #$70
35A2 27 02              BEQ     GETEX
35A4 32                 PUL A
35A5 3F                 SWI
35A6 32         GETEX   PUL A
35A7 F6 1001            LDA B   ACIAXR
35AA C4 7F              AND B   #$7F
35AC 32                 PUL A
35AD 39                 RTS
                ***************************************
                *  DLAY SUBROUTINE
                *
35AE 37         DLAY    PSH B
35AF 86 03              LDA A   #3
35B1 C1 0D              CMP B   #$0D
35B3 26 02              BNE     DLAY1
35B5 86 13              LDA A   #19
35B7 C6 7F      DLAY1   LDA B   #$7F
35B9 BD 3575            JSR     PUTC
35BC 4A                 DEC A
35BD 26 F8              BNE     DLAY1
35BF 33                 PUL B
35C0 39                 RTS
                ***************************************
35C1 CE 286E    INP     LDX     #BUFFR
35C4 BD 3597    INP1    JSR     GETC
35C7 BD 3575            JSR     PUTC
35CA C1 0A              CMP B   #$0A      LF
35CC 27 F3              BEQ     INP
35CE E7 00              STA B   0,X
35D0 08                 INX
35D1 C1 0D              CMP B   #$0D
35D3 26 EF              BNE     INP1
35D5 39                 RTS
                ****************************************
                *  PRTDEC
35D6 36         PRTDEC  PSH A
35D7 37                 PSH B
35D8 FF 28A4            STX     SAVE+2
35DB CE 2952            LDX     #K10
35DE 5F         CVHTD1  CLR B
35DF A0 00      CVHTD2  SUB A   0,X
35E1 25 03              BCS     CVHTD4
35E3 5C                 INC B
35E4 20 F9              BRA     CVHTD2
35E6 AB 00      CVHTD4  ADD A   0,X
35E8 CA 30              ORA B   #$30
35EA 8C 2953            CPX     #K10+1
35ED 27 06              BEQ     CVHTD5
35EF C1 30              CMP B   #$30
```

```
35F1 26 02                BNE      CVHTD5
35F3 C6 20                LDA B    #$20
35F5 BD 3575 CVHTD5 JSR      PUTC
35F8 08                   INX
35F9 8C 2854              CPX      #K10+2
35FC 26 E0                BNE      CVHTD1
35FE 16                   TAB
35FF CA 30                ORA B    #$30
3601 BD 3575              JSR      PUTC
3604 FE 2884              LDX      SAVEX2
3607 33                   PUL B
3608 32                   PUL A
3609 39                   RTS
```

```
                         ****************************************
                         *
                         *******************************************
                         ***  FCC EVENT RECOGNITION ROUTINES  ***
                         *******************************************
                         *
                         **********************************
                         ***  FCC 4 - ROTOR START/STOP  ***
                         **********************************
                         *
3608 CE 0000 F4    LDX     #CVL      SETUP INDEX
360B 6F 3D         CLR     61,X      SET CONE=1
360D 6F 3E         CLR     62,X
360F 86 01         LDA A   #1
3611 A7 3C         STA A   60,X
3613 6D 0B         TST     11,X      ARM?
3615 27 11         BEQ     F4A       NO,BR
3617 6D 05         TST     5,X       RPM<100?
3619 2C 13         BGE     F8        NO,BR
361B 5F            CLR B
361C CE 00F9       LDX     #249      ROTOR CYCLES
361F 86 3C         LDA A   #60       CONSTANT "1"
3621 BD 39A9       JSR     BUMPN     COUNT CYCLE
3624 6F 0B         CLR     11,X      REARM
3626 20 06         BRA     F8
3628 6D 05   F4A   TST     5,X       RPM>200?
362A 2F 02         BLE     F8        NO,CONTINUE
362C 63 0B         COM     11,X      ARM
                         *
                         ***********************************************
                         ***  FCC  8-10 - NORMAL LANDINGS            ***
                         ***  FCC 92-94 - AUTOROTATIVE LANDINGS      ***
                         ***********************************************
                         *
362E 6D 06   F8    TST     6,X       GROUND?
3630 27 1F         BEQ     F86       NO,BR
3632 6F 3B         CLR     59,X      CLR AIRTIME
3634 6D 0D         TST     13,X      AIR SET?
3636 27 35         BEQ     F1        NO,BR
3638 A6 0C         LDA A   12,X
363A 81 64         CMP A   #100      TQ TIMER>=10 SEC?
363C 2D 05         BLT     F8D       NO,BR
363E CE 0000       LDX     #0        NORMAL LNDGS
3641 20 03         BRA     F8E
3643 CE 0006 F8D   LDX     #6        AUTOROTATIVE LNDGS
3646 86 3C   F8E   LDA A   #60       CONSTANT "1"
3648 BD 39A4       JSR     BUMP      COUNT LANDING
364B 6F 0D         CLR     13,X      SET GND
364D 6F 0C   F8F   CLR     12,X      CLR TQ TIMER
364F 20 1C         BRA     F1
3651 A6 3B   F86   LDA A   59,X
3653 81 63         CMP A   #99       AIRBORNE FOR >10 SEC?
3655 2E 05         BGT     F8H       YES,BR
3657 4C            INC A             BUMP AIRTIME
```

```
01232 365A A7 3B          STA A  59,X
01233 365C 20 11          BRA    F1
01234 365E 86 01     F8H  LDA A  #1
01235 3660 A7 0D          STA A  13,X      SET AIR
01236 3662 6D 03          TST    3,X       TQ>5?
01237 3664 27 E9          BEQ    F8F       NO,BR
01238 3666 A6 0C          LDA A  12,X      INC TQ TIMER
01239 3668 81 64          CMP A  #100
01240 366A 27 03          BEQ    F1
01241 366C 4C             INC A
01242 366D A7 0C          STA A  12,X
```

```
                    *
                    ******************************************
                    ***  FCC   1-3 - FLIGHT CLOCK TIME     ***
                    ***  FCC 77-79 - CLOCK TIME IN AUTOROTATION  ***
                    ******************************************
                    *
366F 6D 0D     F1      TST     13,X      AIR CONDS?
3671 27 37             BEQ     F1N       NO,BR
3673 CE 0096           LDX     #150      FLIGHT TIME
3676 86 3C             LDA A   #60       CONSTANT "1"
3678 BD 39A4           JSR     BUMP      COUNT FLIGHT TIME
367B 6D 03             TST     3,X       TQ>5?
367D 27 0C             BEQ     F1C       NO,BR
367F 6C 0E             INC     14,X      INC T77 CNTR
3681 6D 02             TST     2,X       ROLL<10?
3683 2C 22             BGE     F1G       NO,BR
3685 6D 07             TST     7,X       NZ<1.3?
3687 2B 2F             BMI     F29       YES,BR
3689 20 68             BRA     F53XX
368B A6 0E     F1C     LDA A   14,X
368D 81 14             CMP A   #20       T77>2 SECS?
368F 2F 02             BLE     F1F       NO,BR
3691 6F 0E             CLR     14,X      CLR T77
3693 6C 0E     F1F     INC     14,X      INC T77
3695 A6 0E             LDA A   14,X      AUTOROTATIVE CLOCK TIME
3697 A7 2C             STA A   44,X
3699 6F 2D             CLR     45,X
369B 6F 2E             CLR     46,X
369D 86 2C             LDA A   #44
369F CE 00CC           LDX     #204
36A2 BD 39A4           JSR     BUMP
36A5 6F 0E             CLR     14,X      CLR T77
36A7 7E 37D4   F1G     JMP     F53Y
36AA 86 2D     F1N     LDA A   #45       CLR MISC FLAGS,CNTRS
36AC CE 000E           LDX     #T77      START AT T77
36AF 6F 00     CLRF    CLR     0,X
36B1 08                INX
36B2 4A                DEC A
36B3 26 FA             BNE     CLRF
36B5 7E 3987           JMP     F95J
```

```
                      *
                      ***********************************
                      ***  FCC 29-40 - GUNNERY RUN DIVES  ***
                      ***********************************
                      *
3688 6D 04      F29       TST      4,X          RD VALID?
368A 2B 39                BMI      F5XX         NO,BR
36BC 7D 0096              TST      DVTABL+52  ROLL=0?
36BF 26 5F                BNE      F29X         NO,BR
36C1 7D 0097              TST      DVTABL+53  NZ=0?
36C4 26 5A                BNE      F29X         NO,BR
36C6 7D 0095              TST      DVTABL+51  Q=0?
36C9 27 55                BEQ      F29X         NO,BR
36CB 6D 04                TST      4,X          RD<1650 FPM?
36CD 27 28                BEQ      F29H         NO,BR
36CF 96 94                LDA A    DVTABL+50  GET VL
36D1 81 02                CMP A    #2           A/S>.95VL?
36D3 26 05                BNE      F29B         NO,BR
36D5 CE 001E              LDX      #30
36D8 20 12                BRA      F296
36DA 4D         F29B      TST A
36DB 2D 0C                BLT      F29D         A/S<=.7VL
36DD 27 05                BEQ      F29C         .7VL<A/S<=.85VL
36DF CE 0018              LDX      #24          .85VL<A/S<=.95VL
36E2 20 08                BRA      F29G
36E4 CE 0012    F29C      LDX      #18
36E7 20 03                BRA      F296
36E9 CE 000C    F29D      LDX      #12
36EC 86 3C      F296      LDA A    #60          CONSTANT "1"
36EE BD 39A4              JSR      BUMP         INC FCC
36F1 20 2D                BRA      F29X
                      *
36F3 20 5D      F53XX     BRA      F53
36F5 20 4F      F5XX      BRA      F5
                      *
                      *
                      ********************************************
                      ***  FCC 11-22 - LOW VELOCITY FLIGHT CONDITIONS  ***
                      ********************************************
                      *
36F7 96 93      F29H      LDA A    DVTABL+49  GET VH
36F9 81 03                CMP A    #3           A/S>.95VH?
36FB 26 05                BNE      F29K         NO,BR
36FD CE 00BA              LDX      #186         A/S>=.95VH
3700 20 EA                BRA      F296
3702 81 FE      F29K      CMP A    #$FE         A/S<.5VH
3704 27 1A                BEQ      F29X         YES,BR
3706 4D                   TST A                 A/S .65VH?
3707 2C 05                BGE      F29M         YES,BR
3709 CE 00A8              LDX      #168         .5VH<=A/S<.65VH
370C 20 DE                BRA      F296
370E 96 95      F29M      LDA A    DVTABL+51  GET Q
3710 81 01                CMP A    #1
3712 2D 0C                BLT      F29X         TQ<=5?
```

```
3714 27 05              BEQ     F29P        5<TORQUE<=44?
3716 CE 00C3            LDX     #195        TORQUE>44
3719 20 D1              BRA     F296
371B CE 00B1 F29P       LDX     #177
371E 20 CC              BRA     F296
3720 CE 00A3 F29X       LDX     #DVTABL+65
3723 A6 00   LOOP1      LDA A   0,X
3725 A7 02              STA A   2,X
3727 09                 DEX
3728 8C 0097            CPX     #DVTABL+53
372B 26 F6              BNE     LOOP1
372D CE 0092            LDX     #DVTABL+48
3730 09      LOOP2      DEX
3731 A6 00              LDA A   0,X
3733 A7 08              STA A   8,X
3735 8C 0062            CPX     #DVTABL
3738 26 F6              BNE     LOOP2
373A CE 0062            LDX     #DVTABL
373D 6F 03              CLR     3,X
373F 6F 04              CLR     4,X
3741 6F 05              CLR     5,X
3743 CE 0000            LDX     #CVL
```

```
                   *
                   ****************************************
                   ***  FCC 5-7 - QUICK STOP DECELERATIONS  ***
                   ****************************************
                   *
3746 6D 09         F5     TST    9,X       PITCH>15?
3748 2F 08                BLE    F53       NO,BR
374A CE 009F              LDX    #159      QUICK STOPS
374D 86 3C                LDA A  #60       CONSTANT "1"
374F BD 39A4              JSR    BUMP
```

```
                        *
                        **************************************************
                        ***  FCC 53-61 - SYMMETRICAL (GUNNERY RUN) PULLUPS
                        **************************************************
                        *
3752 6D 04      F53     TST    4,X      CRD VALID?
3754 2B 5A              BMI    F53S     NO,BR
3756 6D 20              TST    32,X     PUFLAG SET?
3758 26 36              BNE    F53N     YES,BR
375A 6D 09              TST    9,X      PITCH<5?
375C 2C 52              BGE    F53S     NO,BR
375E C6 01              LDA B  #1       SET PUFLAG
3760 E7 20              STA B  32,X
3762 6D 04              TST    4,X      PD>1650?
3764 26 02              BNE    F53C     YES,BR
3766 E7 30              STA B  48,X     SET NOPUFG
3768 A6 08      F53C    LDA A  8,X      SAVE GW
376A A7 32              STA A  50,X
376C A6 00              LDA A  0,X      SAVE VL
376E A7 33              STA A  51,X
3770 C6 06              LDA B  #6       START LOOP
3772 86 35              LDA A  #53
3774 B7 377B            STA A  F53E+1
3777 CE 0062            LDX    #DVTABL
377A A6 00      F53E    LDA A  0,X      NZ(-X)>1.3?
377C 2C 0D              BGE    F53H     YES,BR
377E 5A                 DEC B
377F 27 0A              BEQ    F53H
3781 B6 377B            LDA A  F53E+1   SET UP NEXT (-X)
3784 80 08              SUB A  #8
3786 B7 377B            STA A  F53E+1
3789 20 EF              BRA    F53E
378B CE 0000    F53H    LDX    #CVL
378E E7 2F              STA B  47,X     SAVE PUFCTM
3790 C6 01      F53N    LDA B  #1
3792 6D 02              TST    2,X      POLL<10?
3794 2C 04              BGE    F53P     YES,BR
3796 6D 03              TST    3,X      TORQUE<5?
3798 26 02              BNE    F53Q     NO,BR
379A E7 30      F53P    STA B  48,X     SET NOPUFG
379C 6C 31      F53Q    INC    49,X     INC PU10
379E A6 31              LDA A  49,X
37A0 81 64              CMP A  #100     PU10=10 SECS?
37A2 27 30              BEQ    F53Y     YES,BR
37A4 6D 09              TST    9,X      PITCH<5?
37A6 2C 0A              BGE    F53T     NO,BR
37A8 6C 2F              INC    47,X     INC PUFCTM
37AA 6D 07              TST    7,X      NZ 1.3?
37AC 2B 02              BMI    F53S
37AE E7 36              STA B  54,X     SET YSPUFG
37B0 20 2C      F53S    BRA    F13
37B2 6D 36      F53T    TST    54,X     YSPUFG SET?
37B4 27 1E              BEQ    F53Y     NO,BR
37B6 6D 30              TST    48,X     NOPUFG SET?
```

```
01427 37B8 26 1A             BNE    F53Y      YES,BR
01428 37BA 6D 33             TST    51,X      CLASSIFY BY VL
01429 37BC 2B 07             BMI    F53TE
01430 37BE 27 0A             BEQ    F53TF
01431 37C0 CE 0030           LDX    #48       A/S>.85VL
01432 37C3 20 08             BRA    F53TG
01433 37C5 CE 0024 F53TE     LDX    #36       A/S<.7VL
01434 37C8 20 03             BRA    F53TG
01435 37CA CE 002A F53TF     LDX    #42       .7VL<A/S<=.85VL
01436 37CD D6 32     F53TG   LDA B  GSV53     GET GW
01437 37CF 86 2F             LDA A  #47
01438 37D1 BD 39A9           JSR    BUMPN
01439 37D4 6F 2F     F53Y    CLR    47,X      CLR PUFCTM
01440 37D6 6F 30             CLR    48,X      NOPUFG
01441 37D8 6F 31             CLR    49,X      PU10
01442 37DA 6F 20             CLR    32,X      PUFLAG
01443 37DC 6F 36             CLR    54,X      YSPUFG
```

```
                    *
                    **********************************************
                    ***  FCC 23-28 - NORMAL (HIGH SPEED) TURNS        ***
                    ***  FCC 41-52 - ASYMMETRICAL PULLUPS             ***
                    ***  FCC 62-70 - GUNNERY TURNS                    ***
                    ***  FCC 71-76 - GUNNERY S-TURNS                  ***
                    ***  FCC 86-91 - HIGH SPEED AUTOROTATION TURNS    ***
                    **********************************************
                    *
37DE C6 01   F13    LDA B  #1
37E0 6D 02          TST    2,X      ROLL>=10?
37E2 2B 74          BMI    F13N     NO,BR
37E4 86 34          LDA A  #52
37E6 BD 398E        JSR    BUMPT
37E9 6D 11          TST    17,X     MODE=X? (0)
37EB 26 14          BNE    F13D     NO,BR
37ED 6D 07          TST    7,X      NZ>=1.3?
37EF 2C 0E          BGE    F13C     YES,BR
37F1 A6 00          LDA A  0,X      SAVE CVH,CVL,CGW
37F3 A7 1A          STA A  26,X
37F5 A6 01          LDA A  1,X
37F7 A7 19          STA A  25,X
37F9 A6 08          LDA A  8,X
37FB A7 1B          STA A  27,X
37FD 20 02          BRA    F13D
37FF E7 15   F13C   STA B  21,X     SET NZE FLAG
3801 6F 11   F13D   CLR    17,X     SET MODE=Y (-1)
3803 6A 11          DEC    17,X
3805 6D 03   F13E   TST    3,X      TQ<5?
3807 27 0F          BEQ    F13F     YES,BR
3809 86 1C          LDA A  #28      INC T86
380B BD 398E        JSR    BUMPT
380E A6 1C          LDA A  28,X
3810 81 14          CMP A  #20      =2 SECS?
3812 26 0A          BNE    F13G     NO,BR
3814 E7 12          STA B  18,X     SET HITQ FLAG
3816 20 06          BRA    F13G
3818 E7 13   F13F   STA B  19,X     SET LOTQ FLAG
381A 6F 1C          CLR    28,X     CLEAR T86
381C 6F 1D          CLR    29,X
381E 6D 14   F13G   TST    20,X     M SET?
3820 26 14          BNE    F13J     YES,BR
3822 A6 02          LDA A  2,X      ROLL>=35?
3824 81 02          CMP A  #2
3826 26 02          BNE    F13H     NO,BR
3828 E7 18          STA B  24,X     SET HI ROLL FLAG
382A 6D 07   F13H   TST    7,X
382C 27 04          BEQ    F13I2    1.3<=NZ<1.5
382E 2B 0C          BMI    F13J1    NZ<1.3,BR
3830 E7 16   F13I   STA B  22,X     SET HI NZ FLAG
3832 E7 17   F13I2  STA B  23,X     SET LO NZ FLAG
3834 20 06          BRA    F13J1
3836 6D 02   F13J   TST    2,X      ROLL>25?
3838 2F 02          BLE    F13J1    NO,BR
```

```
383A E7 2B              STA B  43,X      SET GTS
383C 6D 06       F13J1  TST    6,X       GND COND?
383E 26 04              BNE    F13K      YES,BR
3840 6D 05              TST    5,X       RPM<100?
3842 2C 11              BGE    F13L      NO,EXIT
3844 86 0F       F13K   LDA A  #15       CLR FLAGS
3846 6F 0F       F13K1  CLR    15,X      AND SET MODE=X
3848 08                 INX
3849 4A                 DEC A
384A 26 FA              BNE    F13K1
384C CE 0000            LDX    #CVL
384F 6F 2B              CLR    43,X
3851 6F 34              CLR    52,X
3853 6F 35              CLR    53,X
3855 7E 390D     F13L   JMP    F80
3858 6D 11       F13N   TST    17,X      MODE=X?
385A 27 F9              BEQ    F13L      YES,EXIT
385C 2B 0F              BMI    F13R      MODE=Y? YES,BR
385E A6 34              LDA A  52,X
3860 81 64              CMP A  #100      10 SECS UP?
3862 27 2E              BEQ    F13RZ     YES,BR .
3864 86 34       F13P   LDA A  #52       INC T23
3866 BD 398E            JSR    BUMPT
3869 A7 11              STA A  17,X      SET MODE=Z (1)
386B 20 98              BRA    F13E
386D 6D 17       F13R   TST    23,X      NZLO SET?
386F 27 D3              BEQ    F13K      NO,BR
3871 E7 14              STA B  20,X      SET M
3873 6D 15              TST    21,X      NZE SET?
3875 26 15              BNE    F13RC     YES,BR
3877 6D 13              TST    19,X      TQLO SET?
3879 27 04              BEQ    F13RA     NO,BR
387B 6D 12              TST    18,X      TQHI SET?
387D 26 0D              BNE    F13RC     YES,BR
387F A6 34       F13RA  LDA A  52,X
3881 A7 2C              STA A  44,X
3883 A6 35              LDA A  53,X
3885 A7 2D              STA A  45,X
3887 86 0F              LDA A  #15
3889 BD 3998            JSR    BUMPT2    ADD T23 TO T23A
388C 6F 34       F13RC  CLR    52,X
388E 6F 35              CLR    53,X
3890 20 D2              BRA    F13P
                 *
                 ** MISC MANEUVERS  GROUP 5   (FCC 86-91)
                 *
3892 6F 11       F13RZ  CLR    17,X      CLR MODE BYTE
3894 6D 13              TST    19,X      TQ LO SET?
3896 27 0E              BEQ    F13T      NO,BR
3898 6D 16              TST    22,X      NZHI SET?
389A 27 05              BEQ    F13S      NO,BR
389C CE 0072            LDX    #114
389F 20 62              BRA    F13ZA
38A1 CE 006C     F13S   LDX    #108
```

```
38A4 20 5D                BRA    F13ZA
                   *
                   ** MISC MANEUVERS  GROUP 1   (FCC 23-28)
                   *
38A6 6D 16         F13T   TST    22,X      NZHI SET?
38A8 26 0E                BNE    F13V      YES,BR
38AA 6D 19                TST    25,X      A/S>=.8VH?
38AC 2F 05                BLE    F13U      NO,BR
38AE CE 00DE              LDX    #222
38B1 20 50                BRA    F13ZA
38B3 CE 00D5       F13U   LDX    #213
38B6 20 4B                BRA    F13ZA
                   *
                   ** MISC MANEUVERS  GROUP 2   (FCC 41-52)
                   *
38B8 6D 18         F13V   TST    24,X      HIGH ROLL SET?
38BA 26 20                BNE    F13Y      YES,BR
38BC A6 1A                LDA A  26,X
38BE 81 01                CMP A  #1        CHK A/S:VL
38C0 2E 15                BGT    F13W2     BR IF A/S>.95VL
38C2 27 0E                BEQ    F13W1     BR IF .85VL<A/S<=.95VL
38C4 6D 1A                TST    26,X
38C6 27 05                BEQ    F13W0
38C8 CE 0036              LDX    #54       A/S<.7VL
38CB 20 36                BRA    F13ZA
38CD CE 003C       F13W0  LDX    #60       .7VL<A/S<=.85VL
38D0 20 31                BRA    F13ZA
38D2 CE 0042       F13W1  LDX    #66
38D5 20 2C                BRA    F13ZA
38D7 CE 0048       F13W2  LDX    #72
38DA 20 27                BRA    F13ZA
                   *
                   ** MISC MANEUVERS  GROUP 3   (FCC 62-70)
                   *
38DC 6D 2B         F13Y   TST    43,X      GUN S-TURN?
38DE 26 15                BNE    F13YA     YES,BR
38E0 6D 19                TST    25,X
38E2 2E 0C                BGT    F13Y2     BR IF A/S>=.8VH
38E4 27 05                BEQ    F13Y1     BR IF .65VH<=A/S<.8VH
38E6 CE 004E              LDX    #78       A/S<.65VH
38E9 20 18                BRA    F13ZA
38EB CE 0054       F13Y1  LDX    #84
38EE 20 13                BRA    F13ZA
38F0 CE 005A       F13Y2  LDX    #90
38F3 20 0E                BRA    F13ZA
                   *
                   ** MISC MANEUVERS  GROUP 4   (FCC 71-76)
                   *
38F5 A6 19         F13YA  LDA A  25,X
38F7 81 02                CMP A  #2
38F9 2D 05                BLT    F13YB     BR IF A/S<.9VH
38FB CE 0066              LDX    #102      A/S>=.9VH
38FE 20 03                BRA    F13ZA
3900 CE 0060       F13YB  LDX    #96
```

```
01608 3903 86 0F    F132A  LDA A  #15
01609 3905 D6 1B           LDA B  SGW      GET GROSS WT
01610 3907 BD 39A9         JSR    BUMPN
01611 390A 7E 3644         JMP    F13K
```

```
                    *
                    **********************************************
                    ***  FCC 80-85 - AUTOROTATION TO POWER TRANSITION  *
                    **********************************************
                    *
390D C6 01          F80     LDA B  #1
390F 6D 03                  TST    3,X         TQ<5?
3911 27 18                  BEQ    F80H        YES,BR
3913 6D 1E                  TST    30,X        LOTQ MODE?
3915 26 08                  BNE    F80G        NO,BR
3917 E7 1E                  STA B  30,X        SET HITQ
3919 6D 01                  TST    1,X         A/S>.65VH
391B 2B 02                  BMI    F80G        NO,BR
391D E7 1F                  STA B  31,X        SET A/S FLAG
391F 6C 21          F80G    INC    33,X        BUMP T80 CNTR
3921 6D 07                  TST    7,X
3923 2B 10                  BMI    F80K        BR IF NZ<1.3
3925 27 08                  BEQ    F80J        BR IF NZ<1.5
3927 E7 22                  STA B  34,X        SET NZ FLAG
3929 20 0A                  BRA    F80K
392B 6F 1E          F80H    CLR    30,X        CLR LO TQ MODE
392D 20 22                  BRA    F80R
392F 6D 22          F80J    TST    34,X        NZ>1.5 FOUND?
3931 2E 02                  BGT    F80K        YES,BR
3933 6F 22                  CLR    34,X        NO,CLR NZ FLAG
3935 A6 21          F80K    LDA A  33,X
3937 81 32                  CMP A  #50         5 SECS ELAPSED?
3939 26 1E                  BNE    F95         NO,BR
393B 6D 1F                  TST    31,X        REQ'D A/S OK?
393D 27 12                  BEQ    F80R        NO,BR
393F 6D 22                  TST    34,X
3941 2B 0E                  BMI    F80R        BR IF NO NZ FOUND
3943 27 05                  BEQ    F80L
3945 CE 007E                LDX    #126
3948 20 03                  BRA    F80M
394A CE 0078        F80L    LDX    #120
394D 86 3C          F80M    LDA A  #60
394F 8D 53                  BSR    BUMP        INC CNTR
3951 6F 1F          F80R    CLR    31,X        CLR FLAGS
3953 6F 21                  CLR    33,X
3955 6F 22                  CLR    34,X        SET NZF TO -1
3957 6A 22                  DEC    34,X
```

```
                    *
                    ****************************************
                    ***  FCC 95 - MISC. HIGH-G MANEUVERS  ***
                    ****************************************
                    *
3959 C6 01          F95    LDA B  #1
395B 6D 23                 TST    35,X      ARM?
395D 27 18                 BEQ    F95F      NO,BR
395F 6D 07                 TST    7,X       NZ<1.3?
3961 2C 1A                 BGE    F95G      NO,BR
3963 6D 24                 TST    36,X      LO A/S SET?
3965 26 0A                 BNE    F95C      YES,BR
3967 86 3C                 LDA A  #60
3969 5F                    CLR B
396A CE 00FB               LDX    #251
396D 8D 3A                 BSR    BUMPN     INCR FCC
396F 20 02                 BRA    F95E
3971 6F 24          F95C   CLR    36,X      CLR LO A/S FLAG
3973 6F 23          F95E   CLR    35,X      REARM
3975 20 10                 BRA    F95J
3977 A6 07          F95F   LDA A  7,X
3979 81 02                 CMP A  #2        NZ>1.7?
397B 26 0A                 BNE    F95J      NO,BR
397D A6 01          F95G   LDA A  1,X
397F 81 FE                 CMP A  #$FE      A/S<.5VH
3981 26 02                 BNE    F95H      NO,BR
3983 E7 24                 STA B  36,X      SET LO A/S FLAG
3985 E7 23          F95H   STA B  35,X      ARM
                    **
                    **
3987 73 000A        F95J   COM    IFLAG     SET DONE
398A 01             WAIT   NOP              WAIT FOR NEXT TIME INTRUPT
398B 7E 34E2               JMP    FLOOPA    (WAI,JMP F4)
```

```
                  *
                  ***********************************
                  *** BUMP SELECTED TIMER (BY 1) ***
                  ***********************************
                  *
398E 36           BUMPT  PSH A
398F 6F 2D               CLR    45,X     SET BAA = 1
3991 6F 2E               CLR    46,X
3993 86 01               LDA A  #1
3995 A7 2C               STA A  44,X
3997 32                  PUL A
3998 A7 28        BUMPT2 STA A  40,X
399A 6F 27               CLR    39,X
399C DE 27               LDX    NDX      GET ADDR OF TIMER
399E 8D 48               BSR    MPBA2    BUMP TIMER
39A0 CE 0000             LDX    #CVL
39A3 39                  RTS             EXIT
                  *
                  ******************************
                  *** FCC TABULATION ROUTINE ***
                  ******************************
                  *
39A4 37           BUMP   PSH B
39A5 D6 08               LDA B  CGW      GET GROSS WEIGHT
39A7 20 01               BRA    BUMP3
39A9 37           BUMPN  PSH B
39AA DF 27        BUMP3  STX    NDX      SAVE ADDEND ADDR
39AC 7F 0025             CLR    ASV
39AF 97 26               STA A  ASV+1
39B1 DE 25               LDX    ASV
39B3 A6 00               LDA A  0,X      MOVE 2ND ADDEND TO BAA
39B5 97 2C               STA A  BAA
39B7 A6 01               LDA A  1,X
39B9 97 2D               STA A  BAA+1
39BB A6 02               LDA A  2,X
39BD 97 2E               STA A  BAA+2
39BF 17                  TBA
39C0 97 29               STA A  SNDX     SAVE GW
39C2 48                  ASL A           CVT TO NDX
39C3 D6 28               LDA B  NDX+1
39C5 C1 96               CMP B  #150     WHICH PREC?
39C7 25 02               BCS    BUMP4    BR IF 2
39C9 9B 29               ADD A  SNDX     MUST BE 3
39CB 9B 28        BUMP4  ADD A  NDX+1
39CD 97 28               STA A  NDX+1
39CF C6 01               LDA B  #1
39D1 D7 27               STA B  NDX
39D3 DE 27               LDX    NDX
39D5 0F                  SEI             DISABLE INTERRUPTS TEMPORARIL
39D6 96 28               LDA A  NDX+1    WHICH PRECISION?
39D8 81 96               CMP A  #150
39DA 24 04               BCC    BUMP5    IF TRIPLE,BR
39DC 8D 0A               BSR    MPBA2    DOUBLE
39DE 20 02               BRA    BUMPX
```

```
01744 39E0 8D 0A   BUMP5  BSR    MPBA3
01745 39E2 0E      BUMPX  CLI            REENABLE INTERRUPTS
01746 39E3 33             PUL B
01747 39E4 CE 0000        LDX    #CVL
01749 39E7 39             RTS            EXIT
```

```
                     *
                     *****************************************************
                     ***  MULTIPLE PRECISION BINARY ADDITION ROUTINE   ***
                     *****************************************************
                     *
39E8 37              MPBA2  PSH B               DOUBLE PRECISION
39E9 5F                     CLR B
39EA 20 03                  BRA    MPBAA
39EC 37              MPBA3  PSH B               TRIPLE PRECISION
39ED C6 01                  LDA B  #1
39EF 36              MPBAA  PSH A
39F0 96 2C                  LDA A  BAA          BYTE 1
39F2 AB 00                  ADD A  0,X
39F4 A7 00                  STA A  0,X
39F6 96 2D                  LDA A  BAA+1        BYTE 2
39F8 A9 01                  ADC A  1,X
39FA A7 01                  STA A  1,X
39FC 5D                     TST B               TRIPLE PRECISION?
39FD 27 06                  BEQ    MPBAX        NO,BR
39FF 96 2E                  LDA A  BAA+2        BYTE 3
3A01 A9 02                  ADC A  2,X
3A03 A7 02                  STA A  2,X
3A05 32              MPBAX  PUL A
3A06 33                     PUL B
3A07 39                     RTS                 EXIT
                     ***************************************************
                     ***************************************************
                     ***************************************************
```

```
2800                 ORG    $2800
2800 41      MES2    FCC    /ALTER PARAMETER? (0-9,N,L) /
281B 00              FCB    0
281C 49      MES3    FCC    /ILLEGAL PARAMETER!/
282E 00              FCB    0
282F 20      MES4    FCC    /    #/
2834 00              FCB    0
2835 45      MES5    FCC    /ENTER PASS COUNT (1-255) /
284E 00              FCB    0
284F 01      K1      FCB    1,10,100
2852 64      K10     FCB    100,10
2854 0001    LOOPCT  RMB    1
2855 0001    COUNT   RMB    1
2856 42      MES6    FCC    /BYTE    WAS     IS/
2868 00              FCB    0
2869 20      MES7    FCC    /    /
286D 00              FCB    0
286E 0014    BUFFER  RMB    20
2882 0002    SAVEX   RMB    2
2884 0002    SAVEX2  RMB    2

                     END

TOTAL ERRORS 00000
```